Copyright, 1938, by the AMERICAN SOCIETY OF NAVAL ENGINEERS.

JOURNAL
OF THE
AMERICAN SOCIETY OF NAVAL ENGINEERS

VOL. 50. MAY 1938. No. 2

The Society as a body is not responsible for statements made by individual members

COUNCIL OF THE SOCIETY
(Under whose supervision this number is published).

Rear Admiral HAROLD G. BOWEN, U.S.N.
Captain J. M. IRISH, U.S.N.
Captain ALBERT NORRIS, U.S.N.
Captain H. T. SMITH, U.S.N.
Captain H. S. HOWARD, (CC), U.S.N.
Captain H. F. JOHNSON, U.S.C.G.
Mr. B. W. BLAIR
Mr. H. B. GREGORY
Commander R. W. PAINE, U.S.N.

STEEL CASTING DESIGN FOR THE ENGINEER AND FOUNDRYMAN.

BY C. W. BRIGGS, METALLURGIST; MR. R. A. GEZELIUS, ASSOCIATE METALLURGIST, AND MR. A. R. DONALDSON, ASSISTANT PHYSICAL SCIENCE AIDE, NAVAL RESEARCH LABORATORY.

NAVY DEPARTMENT
BUREAU OF ENGINEERING
WASHINGTON, D. C.

My dear Commander:

The Director of the Naval Research Laboratory has just brought to my personal attention one of the reports of the Laboratory which has just been made to the Bureau. It is a report entitled "Steel Casting Design for the Engineer and Foundryman," prepared by Mr. C. W. Briggs, Metallurgist; Mr. R. A. Gezelius, Associate Metallurgist, and Mr. A. R. Donaldson, Assistant Physical Science Aide.

While the work done by these gentlemen represents several years of intensive study, considerable travel and consultation work, and a carefully planned series of laboratory experiments, which was requested by the Bureau of Engineering so that it might be used as a guide in the formulation of specifications to govern casting purchase, it has occurred to me after studying the report that a wide release of it to industry might offer returns to the Navy in pointing the way toward improved foundry practice, far beyond its particular usefulness to the Bureau.

I am forwarding a copy of the report to you, therefore, requesting you to give careful consideration to the desirability of publishing it in a forthcoming number of the JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS. *You will observe that it contains nothing which could in any way be construed to be confidential, and that it has been prepared in a manner which should definitely appeal to any layman or technician, interested in the rules which should be followed to improve, or secure, a sound casting technique.*

*If you decide to publish it, I would also appreciate it if you will arrange to free the article of your normal copyright restrictions in such a manner as to permit its free use and publication in any trade journals which may care to reproduce it in whole or in part.**

Very respectfully,

H. G. BOWEN,
Rear Admiral, U. S. Navy,
Engineer in Chief.

Comdr. R. W. Paine, U. S. N.,
The Secretary-Treasurer of the
American Society of Naval Engineers.

ABSTRACT.

Steel casting design has been considered from two viewpoints, namely, that of the designing engineer and that of the foundryman. A code or the nucleus of a set of rules is presented for the engineers' guidance and experimental results on padding, external

* The Society authorizes reproduction of this article in whole or in part by interested trade journals.

and internal chills, and controlled directional solidification are reported as of possible interest to foundrymen.

PART I.

THE DESIGNING ENGINEER AND STEEL CASTING DESIGN.

INTRODUCTION.

It is the plan, in this section, to introduce to the designing engineer the concepts of steel casting design in a logical manner, simplified as much as possible.

It is felt that a discussion of design features at this time is appropriate, as the requirements for new equipment operating under higher pressures and at higher temperatures are calling for new designs. Also, requests for reductions in weight have introduced casting problems which require more tolerant design. These new demands have resulted in reductions in wall thicknesses which have, in some cases, produced wall sections that are but small fractions of those formerly employed.

The reduction of wall thicknesses, to effect weight savings, is causing considerable thought and drawing much attention (among consumers and foundrymen) to the internal condition of castings. Defects that were once hidden by very heavy sections are now brought to light. Also, weight savings have reduced the factor of safety and more concern is being given to the integrity of the castings. Castings that operate under high pressures and temperatures are now required to be absolutely homogeneous, and non-destructive testing methods, especially X-ray and gamma ray inspections, are being frequently used to check on the internal conditions. Thus, many things have combined to make the producer and the consumer more conscious of the internal integrity of the casting.

In general, it may be said that most of the defective castings are due to poor design, but as there are no assembled data on design, one can hardly blame the designing engineers for these undesirable conditions.

DIFFICULTIES DUE TO POOR DESIGN.

It might be most appropriate to point out to the designer those defects that occur in steel castings because of poor design. Both hot tears and shrinkage cavities are prevalent in poorly designed

castings. Hot tears form due to large temperature differences in castings where excessive internal stresses cause members to separate or crack at temperatures slightly below the steels' solidification temperature. Cracks occur at abrupt changes in section and at sharp angles.

Shrinkage cavities are due to insufficient metal to care for metal contraction at the time of casting solidification. They are found in sections that must be fed through smaller sections.

Even though the above discussion may mean little or nothing to the designer, it is sufficient to point out, regardless of the terms employed, that internal stresses and contraction phenomena can not be disregarded in the planning of a design from which may be produced a perfect casting. It also should be added that the mechanical properties of the casting will vary with size of section designed. This point will be discussed later at greater length.

DESIGNING TO PREVENT HOT TEARS.

There are two ways in which the designer may prevent the possibility of his embryo casting from cracking or being subject to hot tear formation. These are:

(1) Eliminating hot spots that are under stresses.

(2) Eliminating the stresses that would act on the hot spots or other points of stress centralization.

In principle, the above points could be more easily stated by merely emphasizing that all stress should be eliminated, since the high stresses are primarily the cause of hot tear formation. Unfortunately, casting stresses can not be eliminated, but under certain circumstances they can be controlled. It is not necessary that the details of stress formulation and action be presented here, as the mechanics have been fully described in other publications. It may be pointed out, however, that because of the temperature-contraction relationship, temperature changes are causes of stress formation. Thus, if hot spots are eliminated, the excessive temperature changes are eliminated, stresses are thus reduced, and hot tear formation prevented.

Under certain conditions the design can not be changed to remove the hot spot. In this case the stresses must be relieved in some

other manner. That can best be discussed by reverting to illustrations. But first, how is a designer to know what hot spots are and where to look for them?

A member of a steel casting solidifies from the sand faces toward the center of the cavity. The rate of solidification for practical application is about the same whether the section be one inch or four inches thick. Thus, if the rate of skin formation is about the same, it naturally follows that it will take the heavier section longer to completely solidify. If it is considered that the thinner section is integrally connected to the heavier section in the casting, it may be pointed out that the thinner section is completely solidified and is cooling, and therefore contracting, while the heavier section is still solidifying. The temperature gradients so established will result in different rates of contraction and hence the formulation of stress. Cracking will occur at the weakest section, which, of course, will be the hottest section.

Thus, reverting to the question " what are hot spots and where are they found," it may be said that hot spots refer to sections of extra mass and they are found at positions of joining sections. One or two examples may be sufficient to crystallize the statement. In a cast wheel, the solid hub, which is much heavier in section than the arms or the rim, is a section of extra mass and is located at a position of joining sections. Thus the hub may unquestionably be spoken of as a hot spot. In the typically designed valve, the flanges or the seat are sections of heavy mass joined to much thinner wall sections and therefore may be termed hot spots.

The above discussion leads to the statement of the first rule of the code:

Rule: An attempt should be made to design all sections in a casting with a uniform thickness.

This rule, if followed, reduces the presence of hot spots in a casting to a minimum. These hot spots are responsible for the setting up of temperature gradients, contraction variations, stress formations and their resultant—the deplorable occurrence of hot tears.

It has been suggested previously that the designer will find that under certain conditions the design can not be changed to remove the hot spot. Such a condition necessitates the application of the

second plan for the prevention of hot tears by design; namely, eliminating the stresses that would act on the hot spots or other points of stress centralization.

In the first place, what may be considered as points of stress centralization? Stresses acting upon a casting usually concentrate at abrupt changes in section or at sharp corners. These positions are structurally weak and coupled with the fact that they are usually hot spots with low mechanical properties, it is easily seen that they are potential positions of hot tear formation.

For example, two sections, which are an integral part of a casting, are joined together in the shape of an X (Figure 1). By inscribed circles, a method proposed by Heuvers,[4] the effective mass can be ascertained.

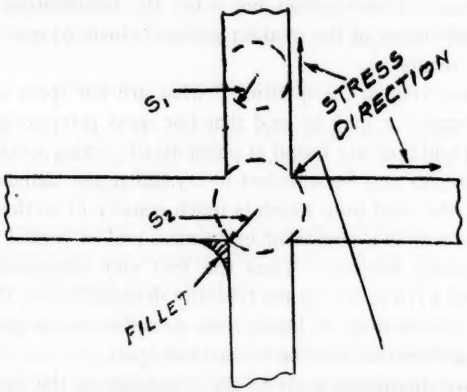


FIGURE 1.—CONCENTRATION OF STRESS AND FORMATION OF HOT TEAR.

If, however, liberal fillets replace the sharp corner junctions the stresses will be more evenly distributed and hot tear formation will be less prone to take place.

In the discussion of fillets for the prevention of hot tears, it should be pointed out that the elimination of hot tears must not be the sole consideration, since an increase in the radius of the fillet also increases the size of the possible shrinkage cavity. Therefore, judgment as to what constitutes an adequate fillet should be reserved until the section of internal unsoundness due to shrinkage has been thoroughly studied.

Abrupt changes in section may be considered analogous to the case described above in that sharp corners, temperature gradients, and stress concentration are similar. On Plate 1 is illustrated how an abrupt change of section can be altered from a poor design to designs that will reduce the possibilities of hot tear formation to a minimum.

The above explanatory notes lead to the statement of further rules of the code:

Rule: It is not desirable to design cast steel structures with abrupt changes in section.

Rule: Sharp corners at adjoining sections are sources of defects, and, if possible, should be eliminated.

The points of stress centralization have been discussed as to their nature and disposition. There is, however, still remaining for discussion that phase pertaining to the elimination of major stresses, which, acting on hot spots, result in the formation of hot tears.

It has already been pointed out that if sections throughout the casting are uniform, major stresses will not arise from excessive temperature gradients and, of course, prominent hot spots will not be present within the casting. Under certain conditions it is impossible to design a casting so that prominent hot spots are eliminated, and, since excessive temperature gradients will thus be present, it becomes necessary to relieve the major stresses resulting therefrom by some other means. The foundryman has at his command a method to reduce these stresses by employing mold relieving principles. The designer can also aid toward producing a more stress-free situation by designing an intricate casting in two, three, or more parts, which are finally assembled into one complete casting by joining the various cast parts by welding.

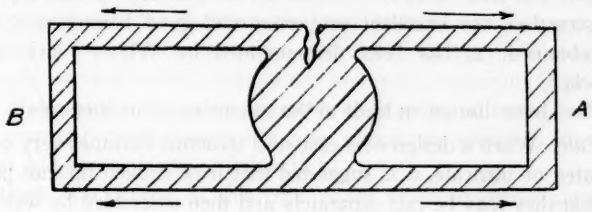


FIGURE 2.

Castings of the weld-assembly design are becoming increasingly popular with design engineers and casting purchasers and are being looked upon quite favorably in the more progressive foundries.

The principles involved in the weld-assembly design are readily discernible to the designing engineer, but for the sake of clarity a simple example will be illustrated.

Figure 2 is a cross section involving two features of poor design; namely, the hot spot and a continuous wall section which would be responsible for hindered contraction stresses set up mainly in the direction of the arrows. A casting so produced would very likely show hot tears in the central section if the foundryman did not take precautionary steps. If, however, the designer eliminated the cross end pieces, A and B, the castings would not be under the major stresses as shown and failure would not be a possibility. The casting could be assembled in the final form by welding previously cast or fabricated sections, A and B, into position.

An actual commercial application of these principles is illustrated in the manufacture of a throttle valve casting. Plate 2 portrays a sketch of the first design of this casting. Considerable trouble was experienced in production and a number of attempts were made before the casting was finally produced without major defects. In Plate 3 the design was altered to the cast-weld-assembly job. All extraneous parts were removed from the base casting, cast separately, and then these parts were welded together to complete the assembly. This casting was produced without defects on the first attempt. It is needless to add that the saving in time and cost of production was considerable.

This principle was extended to the turbine casting as illustrated on Plates 22 to 26.

It is felt that designers should not be alarmed by this type of construction, for excellent properties and good homogeneity can be obtained, as has been demonstrated by White, Clark, and Crocker.[1]

The above discussion leads to the statement of another rule:

Rule: When a design of a cast steel structure becomes very complicated or intricate, it is suggested that it be broken up into parts so that they may be cast separately and then assembled by welding or bolting.

DESIGNING WITH A SINE WAVE CONSTRUCTION.

There is another design feature that should be mentioned in regard to the relief of stresses in an enclosed cast structure. This design calls for the use of members that are slightly waved.

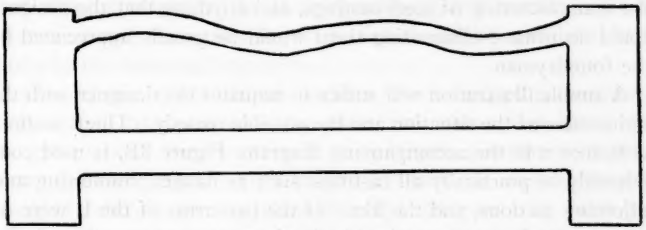


FIGURE 3A.

In the above system the heavy flanges and two different sizes of connecting members will all cool at different rates, and thus the system will be under considerable internal stress. The small member designed with a wave in it, under the tension stresses of the system, will be pulled toward the shape of a straight member and therefore dissipates the internal stresses without tearing, a condition that could not result if the connecting member were straight.

Whether or not this type of a design is adequate to care for required stiffness needed is not known, and is a point that designers themselves must settle. However, from the foundry viewpoint, such a design is appropriate and very useful as a method of stress relieving in an enclosed system.

DESIGNING TO PREVENT CONTRACTION CAVITIES.

When liquid steel solidifies it contracts about 3 per cent in volume, and since steel solidifies progressively from the mold surface toward the center of the mold cavity, a pipe or contraction cavity will result unless the section is fed from some reservoir containing liquid steel. If, however, the section is unable to draw liquid metal from other sources because these inlets have completely solidified, then a defect will appear in the unfed section.

Castings with defects of this type, under vibratory stress aided by stress centralization, may develop cracks extending from the

cavity to the casting face. If the casting is operating under pressure, leaks may develop.

In general, the problem of removing the possibilities of defects due to contraction results in the elimination of the hot spots in castings. These isolated hot spots are sources of great trouble in the manufacturing of steel castings, and anything that the designer could do toward eliminating them would be greatly appreciated by the foundryman.

A simple illustration will suffice to acquaint the designer with the seriousness of the situation and the possible remedy. The L section, as is shown in the accompanying diagram, Figure 3B, is used considerably in practically all castings, such as flanges, connecting and adjoining sections, and the like. If the two arms of the L were of the same thickness, it may be seen by the method of inscribed circles

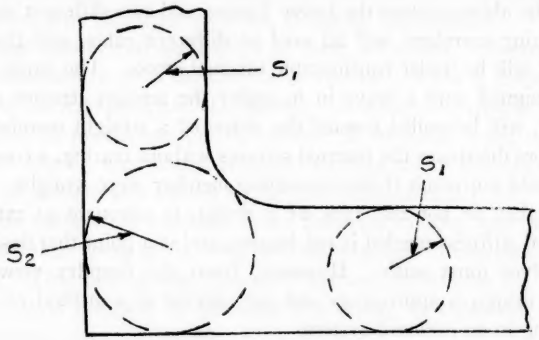


FIGURE 3B.

that where the two legs of the L join, a hot spot will be located. If this hot spot (S_2) can only be fed through the two legs of the L section, one may be certain that when the casting has solidified, since the leg sections solidify first, there will be a cavity somewhere near the center of the inscribed circle, S_2.

If, however, the L section were in a location where the junction could be fed directly by an outside reservoir, instead of attempting to feed through the legs, then the section at S_2 would be sound and contain no cavity.

There are numerous occasions unfortunately when such a joining section can not be fed by an outside reservoir of metal due to its inaccessibility, such as at the bottom of the mold or an internal section of the mold. There is no special problem with joining sections or hot spots that can be fed directly, and design features are not very important as far as safeguards against cavities are concerned; but sections that can not be fed should be considered carefully by the designing engineer.

One of the most difficult features about designing to prevent contraction cavities is to know when and where feed heads may be placed, since their position is quite largely a matter of opinion among foundrymen. As a matter of fact, the casting may be molded contrary to any plans that the designer may have had. Thus, the casting may better be designed with the supposition in mind that none of the metal conjunctions or hot spots can be fed from outside reservoirs. With this point in view, experimentation was carried on with joining sections to determine the extent of the contraction cavity with the change in design.

There are only five ways in which sections may joint. These may be exemplified by the following letters of the alphabet: L, T, V, X, and Y. All other modes of connection are merely modifications of the above possibilities. Designs in the forms of these letters have been studied in detail.

Patterns were made of 3 × 3-inch cross section. The arms were about two feet long and headed at the extreme end. They were poured through the feed heads on the arms. In order that no variations should be overlooked during pouring, studies were made by pouring through one arm, and through two arms at the same time. Molding was according to the dry sand practice and plain carbon basic electric steel was used, poured from a teapot ladle. The sections were all poured in the horizontal position.

It has been stated that in these studies a 3-inch section was used. The reasons for choosing this section were:

(1) A large section would exhibit pronounced defects.

(2) A 3-inch section is not uncommon in structural castings.

(3) With the large section, the conditions of sand and steel would not be so critical and more comparable results could be obtained.

It is felt that the points illustrated in the design charts will be of a comparable order in sections other than those of three inches, and that information obtained on a 3-inch section can be used in the design of other adjoining sections.

The sections were modified by using radii of different sizes in the corners and the effect of the changes was noted. For the purpose of this work it has been assumed that the section studied is located in the casting in such a manner that no feeding is possible except through the arms. Therefore, these arms have been extended about two feet and the only feeding heads provided were those at the end of each arm.

The depth of the section has, of course, no bearing upon the shape of the defect in the plan view as long as the depth is great enough to permit a defect to form. Even if the depth of the section were infinite, the plan view of the defect should, theoretically, remain the same.

After the sections were cast they were radiographed. Castings were radiographed with radium at a distance of 40 inches with a 2-millimeter source of focal spot in order that the defects would appear in their natural sizes on the film. The defects exhibited in the radiograph were then reduced photographically so that the defect drawn on the small diagrams presented in this report would be shown in their correct proportion. Reproductions of two radiographs are included to illustrate the general characteristics of the defects found (Plates 20 and 21). Plate 20 is a radiograph of a 3 × 3-inch T section and Plate 21 is a radiograph of a section taken from a commercial casting.

It is now suggested that the designer turn to the charts illustrating the various sections. The charts are self-explanatory and from them may be obtained several features of design. See pages 215 to 224. (Plates 4 to 13.)

In discussion of the L section, it may be said that if the outside corner at the junction is maintained, an increasing radius at the inner corner will bring about an increasing size of defect. If the section is uniform throughout, a defect will be found if the inner radius is small. If the inner radius is increased, but a uniform section is maintained, the defect will become smaller until it develops

into center line weakness, a condition apt to be found in uniform sections of any length.

Sections of the L type should not have less than ½-inch inside radius, and only in a few cases would a 3-inch inside radius be used. The best common practice therefore appears to be one in which radii of ½ inch to 1 inch would be used.

The practice of designing the section at the junction slightly smaller than that of the arms appears to give the best results.

The only way in which a T section can be designed without being responsible for a contraction cavity is to core a hole at the center of the junction of the two members. Depressions in the arm of the T, while not eliminating the defect, do reduce it markedly from that found in the common T design.

Since the size of the defect increases with the size of the radius, it is recommended that a radius of ½ inch, and not over 1 inch, be used.

It has been suggested from time to time by those writing on the subject of design, that if the leg of the T section were made smaller in section to that of the arm, that the hot spot, and hence the size of the cavity, would be reduced. This is true, as is illustrated in 202, 209, 210, and 211. It should also be pointed out, however, that as the leg section decreases, the temperature differential between the two sections increases, and stresses are formed that may result in the formation of hot tears. Thus, care should be used in designs of this type so as not to incorporate them in enclosed stress active systems.

A uniform section in the shape of a V will not be free from contraction cavities, since a synthetic hot spot is developed at the junction due to the fact that the sand is not able to conduct heat away from the three inside faces as fast as it can from the single outside face. It will be noticed that if the inner radius is increased, as in 305, that the defect will be smaller than in a comparable case such as 302. As in the case of the L design, a slightly reduced section at the junction of the members is necessary for a homogeneous section. In designing V sections, it is suggested that an inner radius not less than one inch be used.

The designer will observe that an X section could not be designed that could be made free from a contraction cavity, if the section

were fed only through the arms. The defect could, however, be made quite small by designing the section with a cored hole as in 504 and 505.

Much has been said in previous discussions upon casting design concerning offsetting the arms of the X so that the hot spot would be reduced. This is not true if the offset is similar to designs 506, 507, and 508. The defects formed by this type of construction are about the same size as would appear in the usual X type section. A section having one arm completely offset, as in 506, allows the foundryman to use external chills to advantage. Slightly better results could be obtained by spacing the offsets further apart, such as illustrated in 509. Such a design allows the foundryman ample freedom for the placing of external chills. Designs 510, 511, and 512 show how the defect may be decreased in size as the adjoining section is decreased. The same principles apply here as they did in the T section that has previously been discussed.

Unless the cored hole at the center of the hot spot is advantageous to use, it is suggested that the one arm offset similar to 509 be used.

An interesting point encountered in the Y section is that no matter how the features of the design are altered, the defect found was about the same size. Attention is called to 403, 404, 405, and 406. The only design without defect was 408. A triangular hole of this type is able to extend to all the hot spots that are possible in the section. Defects found in sections of commercial casting 409, 410, and 411 are exhibited for sake of comparison. Occasionally there appears a design wherein an area of heavy metal is attached on all sides to members of much smaller thickness and so located that the foundryman has no opportunity to properly feed the heavy portions by means of a conveniently placed feed reservoir. Such a condition is distinctly one of poor design. The heavy section should either be cored or more closely investigated to ascertain if it could not be made lighter.

A study of all these various sections leads to a few general rules:

Rule: In designing unfed joining sections in L or V shapes, it is suggested that all sharp corners at the junction be replaced by radii so that this section becomes slightly smaller than that of the arms.

Rule: In designing sections that joint in an X section, it is suggested that two of the arms be offset considerably.

Rule: In designing any joining sections, it is suggested that all sharp corners at the junctions be replaced by radii. In the case of unfed T and X sections these radii should not be large.

It may be pointed out that in connection with joining sections that it is the custom of designers to use webs, brackets, and ribs between various parts of the casting to impart a certain amount of rigidity or stiffness to the casting. Such stiffing members should be kept to a minimum as they are sources of considerable trouble both as to the formation of hot tears and shrinkage cavities. The placing of brackets across joining sections of course increases the mass effect at the intersection of the adjoining members and the bracket. This undesirable condition may be remedied by the extensive coring of the bracket in the region of the adjoining sections. Such coring will not impair the stiffing features of the bracket and will at the same time allow for better conditions of homogeneity of the adjoining sections.

It is the desire of the authors before leaving this section entirely, to impress upon the designer two things, one of which is that the sections which have been illustrated were not fed, and had it been possible to attach a reservoir of liquid metal to the sections they would have been free from contraction cavities. The foundryman will go to considerable trouble to feed these sections. It is only those that are located in impossible positions that he fails to reach. The second point to be stressed is that even though the designer is unable to design a section which if unfed will be free from contraction cavities, he can design it so that it will have, under the circumstances, the smallest cavity possible. Then with this design the foundryman can apply the tools and knowledge at his command such as the use of padding, external or internal chills to make the section homogeneous.

It is suggested that the designer look over the charts on adjoining sections in the foundryman's portion of this report so that he may see what can be accomplished by chilling unfed sections.

THE EFFECT OF MASS UPON THE MECHANICAL PROPERTIES OF CAST STEEL.

The effect of mass upon the mechanical properties of cast steel is a subject that is of practical importance to designing engineers,

particularly those engaged in designing power plant equipment where steel castings are being installed in systems subject to greater pressures and higher temperatures than those previously used. Engineers have relied upon data collected on the properties of cast steel, such as that assembled by Lorig and Williams.[2] They realize, as was noted by Lorig and Williams, that such data are rarely complete in that the chemical analyses, size of casting, heat treatment, size of the specimen or the method of testing are not always known. As many of the data are obtained from laboratory heats produced under ideal conditions, the results may not be comparable to those obtained in a commercial casting. In commenting on this condition, Sisco, in his volume of the Alloys of Iron Monographs, pointed out that of all the variables which may affect the mechanical properties of cast steel, and one which is seldom mentioned in the compilation of data, the effect of mass is clearly the most important.

TESTING METHODS.

A study of the previous work on this subject shows that no data have been reported upon the effect of mass on the mechanical properties of cast steels in both the as-cast and annealed conditions. As the designing engineer should have some indication of what may be expected as mechanical properties in various sections, it was deemed advisable to study this effect. It should be noted, however, that these data can refer only to the analyses studied and can only be indicative of the properties of other cast steels produced in similar sections.

In order to study the effect of mass upon the mechanical properties, well-fed coupons were cast horizontally in medium carbon steel and medium manganese steel. The coupons were all 12 inches long and those cast in medium carbon steel were ½ × ½ inch, 1 × 1 inch, 2 × 2 inches, 3 × 3 inches, 4 × 4 inches, and 8 × 8 inches in cross section. Only the 1 × 1 inch, the 3 × 3 inch and one 8 × 8 inch coupons were cast in medium manganese steel for these tests. Each coupon was top poured through the feed head. The feed heads, along the entire upper faces of the coupons, were large enough to permit the shrinkage cavities to form within them without extending into the coupons. The feed heads were sawed

Table I

The Effect of Mass Upon the Mechanical Properties of Medium Carbon Cast Steel

Specimen		Yield Point Lbs. Per Sq. In. As Cast	Yield Point Lbs. Per Sq. In. Annealed	Tensile Strength Lbs. Per Sq. In. As Cast	Tensile Strength Lbs. Per Sq. In. Annealed	Per Cent Elongation As Cast	Per Cent Elongation Annealed	Per Cent Reduction in Area As Cast	Per Cent Reduction in Area Annealed
Center ½" Block	A	38,200	49,000	77,600	75,450	25	30	35	47
Center 1" Block	B	.....	48,000	75,500	75,000	25	28	30	46
Center 2" Block	C	.....	46,750	73,000	74,500	21	30	26	40
Top 3" Block	D	.....	44,750	71,750	71,500	18	28	19	35
Center 3" Block	E	.....	45,200	72,300	72,000	20	29	23	39
Bottom 3" Block	F	.....	45,000	74,000	72,400	21	28	26	40
Lower Corner 3" Block	G	.....	45,250	73,500	73,250	23	29	30	42
Top 4" Block	H	.....	45,250	71,000	70,000	15	29	21	43
Center 4" Block	I	.....	44,500	71,200	70,500	19	29	23	39
Bottom 4" Block	J	.....	45,750	73,250	72,250	22	30	21	46
Lower Corner 4" Block	K	.....	45,500	73,700	73,000	25	30	33	46
Top 8" Block	L	.....	41,750	70,000	70,125	8	26	9	40
Center of upper half 8" Block	M	.....	43,000	71,000	68,250	9	26	9	40
Center 8" Block	N	33,500	42,000	70,500	68,500	9	27	10	36
Center of lower half 8" Block	O	.....	41,750	74,250	68,750	16	28	18	41
Bottom 8" Block	P	.....	43,750	76,100	70,750	18	29	21	44
Lower Corner 8" Block	R	.....	43,500	76,750	72,125	22	29	30	44

Table II

The Effect of Mass Upon the Density of Cast Steel

Location of Specimen	Density
Center 1-Inch Coupon	7.8379
Center 3-Inch Coupon	7.8306
Top 8-Inch Coupon	7.8106
Center 8-Inch Coupon	7.8114
Bottom 8-Inch Coupon	7.8122
Lower Corner 8-Inch Coupon	7.8175

Table III

Chemical Analyses of Sections of Medium Carbon Steel

Location of Specimen	Per Cent Carbon	Per Cent Manganese	Per Cent Silicon	Per Cent Aluminum
Center 1" Coupon	0.270	0.634	0.212	0.035
Top 8" "	0.265	0.634	0.229	0.028
Center 8" "	0.243	0.623	0.228	0.040
Corner 8" "	0.268	0.637	0.230	0.032

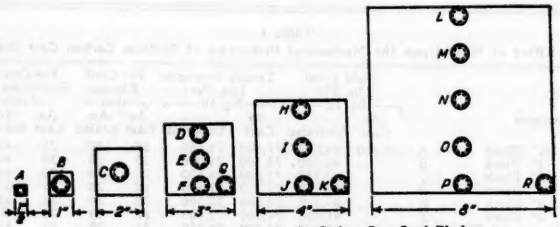


Fig. 4—Location of Test Bars in the Carbon Cast Steel Blocks.

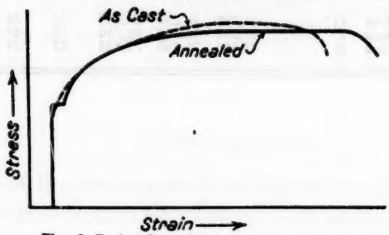


Fig. 5—Typical Stress-Strain Curves for Carbon Cast Steel.

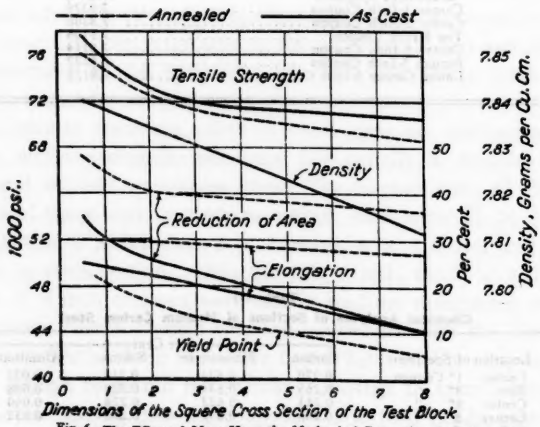


Fig. 6.—The Effect of Mass Upon the Mechanical Properties of Carbon Cast Steel at the Center of the Test Block.

from the coupon prior to heat treating. One coupon of each size was annealed at 900 degrees C. (1650 degrees F.) for the customary time of one hour per inch of section. The coupons were then cut and tensile specimens machined from the locations shown in Figure 4. The specimens were all standard 0.505-inch diameter tensile specimens, except those machined from the ½ × ½ inch coupon. These specimens were 0.313 inch in diameter with a gauge length of 1.25 inches.

After the tensile tests were obtained, specimens were machined from the threaded portion of the bars for micrographic studies, density measurements and chemical analyses.

In another heat, bars ½, 1, 2, and 3 inches in diameter and coupons similar to those mentioned previously were cast from low carbon steel. One-half of the bars and one-half of the coupons were annealed as before. Tensile test bars were machined from the coupons and tested. The bars were tested in the unmachined condition in order that some indication of the actual strength of cast sections might be obtained.

MASS EFFECT ON MEDIUM CARBON CAST STEEL.

The data obtained from the tensile specimens machined from the medium carbon cast steel at the locations shown in Figure 4 are given in Table I. It will be noted that the yield point in the as-cast condition is listed in only a few instances. The representative stress-strain curve (Figure 5) shows that in the as-cast condition, cast steel has no marked yield point. The yield point must therefore be determined from a stress-strain curve. The data of Table I together with the density data as set forth in Table II are shown diagrammatically in Figure 6.

The most outstanding feature exhibited by the curves is the sharp bends that are found in the tensile, yield and reduction of area curves in the neighborhood of the 2-inch section. In general, all of the mechanical properties in the 8-inch section were lower than those found in the ½-inch section. However, the loss was not as great in the annealed state as it was in the as-cast condition. The density curve also shows a drop in value as the mass of the test block increases.

If the properties of any one section are considered, it may be noticed that the lowest results are obtained at the center of the sec-

tion and the highest in the bottom corners where solidification has proceeded from two faces. The corner results are usually higher than those obtained elsewhere along the bottom where there is only one solidifying face. These conditions are more pronounced, of course, when the steel is tested in the as-cast condition, but they are also noticeable in the heat treated material.

Since the mechanical properties varied to such a considerable degree, it was thought that perhaps segregation of chemical compositions was responsible for a large portion of the difference. Phosphorus and sulphur segregations were studied in the various sections by etching and sulphur prints, but no differences could be ascertained. This was perhaps due to the fact that they were both present in very low amounts in the steel as cast. As the steel was made by the basic process, these analyses were 0.02 per cent for the phosphorus and 0.03 per cent for sulphur. Segregation was also studied by chemical analysis. The centers of each section were analyzed for carbon, manganese, silicon and aluminum and the results are set forth in Table III. The greatest difference appeared in the carbon content where 0.03 per cent was noted. The center of the 1-inch coupon contained 0.27 per cent, while the center of the 8-inch coupon contained 0.24 per cent. The manganese, silicon and aluminum analyses showed that there was practically no segregation of these elements.

The specimens were also studied microscopically in the unetched condition to see if the inclusions had formed an aluminum network which might tend to lower the physical properties in the larger cast sections. No network was evident. The inclusions were, however, slightly larger and fewer in the centers of the heavier sections.

It appears from the above study that there are three conditions that bear upon the mechanical properties as affected by mass. These are: (*a*) the density, (*b*) the carbon segregation, and (*c*) the microstructure. It is difficult to ascertain from the data which of these is the most important. As the section increases, the density drops, the carbon content drops and the grain size increases. In regard to the tensile strength and yield point values, the microstructure and the carbon segregation are probably the most important in causing the lower values. The density and the microstructure are responsible for the lower ductility found in the heavier

sections. From this it appears that the microstructure is the dominant controlling factor.

The properties listed at the center of the section are the poorest ones present in this section. The average properties over the entire section are better than those exhibited by the center, due to the preponderance of material having better properties, such as those exhibited by the corners and edges.

THE MASS EFFECT IN MEDIUM MANGANESE STEEL.

The effect of mass upon the mechanical properties of the medium manganese steel studied (Figure 7) is similar to that found in the medium carbon steel. In each case the mechanical properties at the center of the test coupon decrease as the mass of the section increases. The variation in the tensile strength is, however, considerably greater in the manganese steel than it is in the plain carbon steel. The tensile strength in the plain carbon steel in the center of the 8-inch coupon is 5000 pounds per square inch less than that in the 1-inch coupon, a crop of 6.5 per cent. In the medium manganese steel the decrease in similar coupons is 10,400 pounds per square inch, a change of 10.5 per cent. It should be noted that the change in the tensile strength of the manganese steel decreases gradually and rather uniformly with an increase in mass, whereas the tensile strength of the plain carbon steel decreases rapidly at first and then at a decreasing rate as the mass increases.

The other tensile properties of the medium manganese steel also decrease gradually and at a more uniform rate than in the plain carbon steels.

The tensile properties of various sections of the 8-inch coupon vary in a manner similar to that found in the plain carbon steel. Table IV indicates that the best tensile properties are found in the lower corner and the bottom of the test coupon. The top of the coupon, immediately under the head, exhibits the poorest properties and the properties then increase gradually toward the bottom of the coupon. The Izod impact strength, however, increases as the mass of the section increases and is greater at the center of the 8-inch coupon than it is in the corner of the coupon.

Chemical analyses were obtained from the center of the 1-inch and 3-inch sections and from the top, center, bottom and corner of

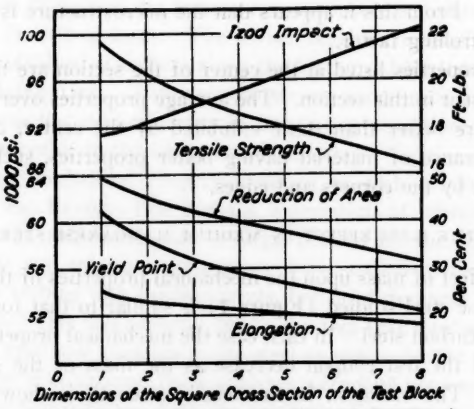


Fig. 7.—Effect of Mass Upon the Mechanical Properties of Medium Manganese Steel at the Center of the Test Block.

Table IV
The Effect of Mass Upon the Mechanical Properties of Medium Manganese Cast Steel

Specimen		Heat Treatment Degrees Fahr.	Lbs. Per Sq. In. Yield Point	Lbs. Per Sq. In. Tensile Strength	Per Cent Elongation	Per Cent Reduction of Area	Ft.-Lbs. Izod
Center	1" Coupon	Annealed 1650—1 hr.	60,750	99,000	25	49	17.7
"	3" "	" 1650—3 hr.	56,750	94,750	22	42	18.6
"	8" "	" 1650—8 hr.	52,250	88,625	18	31	22.3
Top	8" "	" 1650—8 hr.	52,750	88,125	18	31	....
Bottom	8" "	" 1650—8 hr.	56,000	95,000	23	41	....
Corner	8" "	" 1650—8 hr.	56,000	95,000	24	50	19.2
Midpoint	8" "	" 1650—8 hr.	55,750	92,250	21	35	....
*C-4		" 1650—1 hr.	61,375	91,375	20	52	....
*C-5		" 1850—1 hr.	56,000	88,650	20	50	....
*D-3		" 2050—1 hr.	58,625	99,125	22	46	14.6
*D-4		" 2250—1 hr.	60,000	99,675	17	36	....
*D-6		" 1850—15 min.	60,650	96,125	22	42	....
*E-4		" 2050— 5 min.	60,750	96,875	22	41	16.3
*E-5		" 2250— 5 min.	.....	99,650	18	40	....
*F4		" 1650—1 hr. 1525—1 hr.	68,250	96,375	22	48	....
*F5		Merten's Treatment	51,500	90,000	25	50	....

*Specimens previously annealed in coupon at 1650 degrees Fahr. for 8 hours.

Table V
Chemical Analyses of Sections of Medium Manganese Steel

Location of Specimen		Per Cent Carbon	Manganese	Silicon	Aluminum
Center	1" Coupon	0.340	1.46	0.322	0.057
Center	3" "	0.323	1.46	0.320	.....
Top	8" "	0.320	1.46	0.319	.....
Center	8" "	0.297	1.41	0.312	0.056
Bottom	8" "	0.333	1.47	0.322	.....
Corner	8" "	0.342	1.48	0.321	.....

the 8-inch section in order that the amount of segregation could be determined (Table V). Segregation of carbon can be seen in that the carbon content at the center of the coupon decreases as the mass of the section increases. The carbon content at the center of the 8-inch section is the same as that at the center of the 1-inch coupon. There is slight segregation of manganese but no segregation of silicon or aluminum.

This segregation of carbon and manganese will probably account for the decrease in tensile strength as the mass is increased.

COMPARISON OF COUPONS AND BARS CAST TO SIZE.

One of the points upon which designers have desired information is the comparison of the mechanical properties of cast steel sections and the properties exhibited by the well-fed coupon. This point was investigated and the results are set forth in Table VI. In this

Table VI
The Comparison of the Mechanical Properties of Well Fed Test Coupons and Bars Cast to Size

		Carbon 0.21	Manganese 0.60		Silicon 0.31			
Section	Gauge Length	Yield Point		Tensile Strength		Per Cent Elongation		Per Cent Red. of Area
		As Cast	Annealed	As Cast	Annealed	A.C.	Ann.	A.C.	Ann.
½" Coupon	Standard Tensile Spec.	.....	44,600	69,800	70,700	29	34	40	50
1" "		.....	42,500	69,000	69,700	28	33	38	48
2" "		.....	41,750	67,000	69,000	20	32	23	44
3" "		.....	40,750	64,500	67,750	18	32	24	40
½" Dia. Bar	2"	.....	43,000	69,000	69,500	11	20	13	25
1" " "	4"	58,500	40,000	67,100	64,600	12	16	12	30
2" " "	8"	54,200	39,200	61,800	64,000	8	13	8	23
3" " "	12"	.....	39,500	.....	63,550	.	14	.	13

experiment, bars were cast in the horizontal position while coupons were cast similar to those used previously. From the center of these as-cast and annealed coupons, standard tensile bars were machined and tested. These specimens likewise showed the effect of mass on the mechanical properties.

The bars were tested in the condition they came from the stand mold except that one set was annealed before testing. The bars were not machined nor were the cast surfaces removed.

The yield and the tensile strengths were nearly the same in both bars and specimens machined from the coupons. The ductility, however, was much lower in the case of the bars. This is undoubtedly due to the rough surface of the bars. The decrease in

ductility with increasing mass is much greater with the bars than it is with the coupons.

These data point out that while the strength properties in cast sections are nearly the same as those represented by the coupon, the ductility properties are much lower and should be borne in mind by the designer. The interesting point is that the ductility results are rather erratic and would depend a great deal on the surface of the casting, and probably on the size of the axial weakness.

The purpose in presenting data on bars cast to size is to inform design engineers of the properties of castings that may have sections similar to those tested. It is requested that the data obtained on the machined test specimen be not directly compared to the data resulting from testing the cast bars, since the latter is a notable variation from the standard test bar and will not give comparable results. The machined specimen taken from the coupon gives an indication of the best properties of the metal. The data obtained from testing the cast bars give an indication of the properties of an actual cast section. It is well known that a rough surface will result in lower ductility values being presented, but it should also be pointed out that most castings are used in commercial installations with the cast surfaces exposed and that the actual mechanical properties of that section as it stands in the installation are more along the lines of the data as presented for the cast bars than they are according to the data collected from the coupon. Thus, the properties are reported as an indication of what the section will withstand and it is not at all a test of the most favorable properties of the steel, nor a direct comparison of two types of test specimens.

The above section on the effect of mass on the mechanical properties of cast steel can be summarized as follows:

(1) There is a loss in strength and ductility, as measured at the center of the section, as the mass increases.

(2) In the carbon steel studied the loss is pronounced for the first two inches of cross section, after which it tapers off gradually. In the manganese steel there is no decided knee to the curve.

(3) There is a decrease in density and carbon content, and an increase in Izod impact value as the mass increases.

(4) Microstructure, carbon segregation and density values are

responsible for the decrease of mechanical properties as the mass increases.

(5) Segregations of silicon, aluminum, phosphorus and sulphur were small and had no apparent effect as to producing low mechanical properties.

(6) The mechanical properties of sections as represented by cast bars show that strengths are quite similar to the optimum values as recorded by the machined test specimens, but that the ductility is much lower.

The above discussion in regard to mass effect leads to the following statement:

Rule: In a general way it may be said that the effect increasing mass has on the mechanical properties is not pronounced and probably is amply covered by the present factor of safety.

SUGGESTED RULES FOR STEEL CASTING DESIGN.

1. An attempt should be made to design all sections in a casting with a uniform thickness.

2. It is not desirable to design cast steel structures with abrupt changes in section.

3. Sharp corners at adjoining sections are sources of defects, and, if possible, should be eliminated.

4. When a design of a cast steel structure becomes very complicated or intricate it is suggested that it be broken up into parts, so that they may be cast separately and then assembled by welding.

5. In designing unfed joining sections in L or V shapes, it is suggested that all sharp corners at the junction be replaced by radii so that this section becomes slightly smaller than that of the arms.

6. In designing sections that join in an X section, it is suggested that two of the arms be offset considerably.

7. In designing any joining sections, it is suggested that all sharp corners at the junctions be replaced by radii. In the case of unfed T and X sections, these radii should not be large.

8. In a general way it may be said that the effect increasing mass has on the mechanical properties is not pronounced and probably is amply covered by the present factor of safety.

PART II.

THE FOUNDRYMAN AND STEEL CASTING DESIGN.

INTRODUCTION.

In discussing the question of design from the foundry viewpoint, only the shape and size of the mold cavity will be considered. The composition of the mold may, of course, affect the soundness of the casting by producing hot tears, porous spots, or sand inclusions. This is in itself a most comprehensive subject, but one which is controlled largely by the type of materials available locally and the sand treating and sand testing equipment at hand. What may be expedient for one foundry may be entirely out of the question for another concern. The mold, therefore, will be considered merely as a medium in which a cavity similar to the finished casting may be produced.

It has been stated previously that the defects that may be attributed to the design of the casting are shrinkage cavities and hot tears. It should be noted that while many hot tears are due to mold composition and the manner of molding, a large portion of the hot tears found in castings are inherent in the casting design and can not be eliminated by mold relieving.

Shrinkage cavities are produced by the contraction of the metal upon solidifying and, theoretically, they can be eliminated only in one manner, i. e., by "controlled directional solidification." Foundrymen have for many years used "directional solidification" and "progressive solidification" as synonymous terms. To the authors, however, each of these terms has a specific meaning and, for the purpose of this discussion, it may be well to define them.

Progressive Solidification. Any liquid metal cooling in a cavity formed in a refractory or metal mold will solidify *progressively* from the mold-metal interface toward the center of the cavity. Thus *progressive solidification* is present in every casting produced.

Directional Solidification. In addition to the *progressive solidification* from the mold-metal interface toward the center of the cavity, solidification will proceed *along* the cast member in the direction of the increasing temperature gradients produced in pouring the casting. These temperature gradients *along* the cast member

appear in both the metal and the mold and are determined by the shape of the mold cavity and the method of gating and heading. They are, therefore, *controllable*, whereas the foundryman has no control over the direction of the temperature gradients producing *progressive solidification*. If this analysis is followed to its logical conclusion it is evident that all shrinkage cavities in castings are the result of adverse temperature gradients, or *uncontrolled directional solidification*. Only when the temperature gradients within the metal and the mold are such that the " feed heads " are the last portions of the casting to solidify, and thus can furnish liquid metal to fill the voids formed during solidification, can a " sound " casting be produced. As in most castings, desirable temperature gradients can be produced by using tapered sections, proper methods of gating and heading, and properly placed chills; it follows that *controlled directional solidification* is the governing factor in the elimination of cavities due to shrinkage.

CONTROLLED DIRECTIONAL SOLIDIFICATION IN THE FOUNDRY.

In the section devoted to " design for the engineer " it was emphasized that designing engineers should endeavor to maintain uniform cross sections throughout the casting. The paragraph above on directional solidification appears to be a direct contradiction of the first statement, as it advocates the use of tapered sections in producing " sound " castings. This apparent contradiction has been placed in this discussion for the reason that the designer can not know how the foundryman will produce his casting, and any tapering of sections that he may provide might produce temperature gradients opposing those that the foundryman finds essential to secure a good casting. If, however, the designer maintains fairly uniform cross sections throughout the casting the foundryman can much more easily produce the temperature gradients he desires.

An illustration of how temperature gradients produced by tapered sections can insure correct solidification is given in the sketch of the turbine casing casting shown in Figure 8. If this casting is poured flange-up, the sections tapered as shown and a rotten core used to forestall hot tears, it is comparatively easy to produce a sound casting. It should be noted that the padding on the cylinder bore is brought down below the steam chamber so that the steam

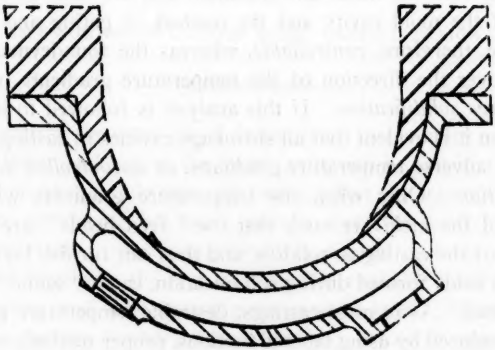


FIGURE 8.

chamber can be fed directly. The casting was poured through the head so that the last metal to enter the mold (hot metal) was in the head. Now, if external chills are placed around the ports of the steam chamber, it can readily be seen that solidification proceeds from the lower portion of the casting toward the heads. This *direction* of *solidification* has been controlled by producing favorable temperature gradients with tapered sections and this casting becomes a comparatively easy one to produce without defects.

Some objection may be raised to the excessive amount of machining required on the bore of the cylinder. This is merely a question of economics. Four of these castings were produced; each one was declared acceptable after a complete gamma-ray inspection. The loss of one casting, produced without the precaution of padding, would have cost more than the total extra machining charges on all four castings.

In many castings, particularly small and medium sized castings, the temperature gradients can be controlled by proper gating and pouring methods. These principles have been very well presented by the late George Batty,[3] and it would be superfluous to discuss them here.

MODELS AS AN AID TO FOUNDRY PRACTICE.

In many cases slight changes in design will enable the foundryman to produce sound castings even when it is almost physically

impossible to make a casting without defects from the original design. It is, at times, difficult to obtain the consent of the customer for even slight changes in design. This is particularly true if the casting is complicated and rather difficult to visualize from blueprints. It may then be advantageous to prepare a model of the original design at an appropriate scale and use this model to point out the difficulties connected with the design and the modifications required to remove or alleviate them.

This method of attack has been used to advantage by the Norfolk Navy Yard in the production of turbine castings. The models shown in this report (Plates 22 and 23) to illustrate their advantages were prepared at the direction of Mr. S. W. Brinson, Master Molder of the Norfolk Navy Yard. Photographs of a completed casting prepared after the design had been modified are shown in Plates 24, 25, and 26. If the photographs of the models and the castings are compared, it will be noted that, while the changes are minor in character, as far as the engineering usefulness of the casting is concerned every effort has been made to obtain directional solidification and to simplify the production of the casting. It may be appropriate to point out a few of the changes that were made.

(A) The base casting was separated at (A) and the high-pressure end was cast separately. This facilitated the production greatly.

(B) The thickness of the gland supporting web was increased and the cored " pockets " eliminated by changing the shape of the web.

(C) The bolt bosses were tapered from top to bottom to facilitate feeding.

(D) The thickness of the steam belt was increased and an opening provided for core anchorage. This opening was later closed by a plate welded on.

(E) The radius at the junction of the flange and web was increased to eliminate a sharp change in section and permit feeding of the sections at the bottom.

(F) The thickness of the web was increased and a larger radius provided to insure proper feeding.

(G) This outlet was cast separately and welded on.

(H) The wall thickness of the steam belt was increased and the outlet was cast separately and welded on. As the castings were to be used as a "right" and a "left," two openings were made to secure proper core anchorage. One of these openings was sealed by a welded cap, the other was welded to the outlet case separately. This permitted the use of identical cores for both the "right" and "left" castings.

(I) The web was cast separately and welded on to the main casting. This web, if cast integrally, would very probably have caused hot tears, which would have had to be repaired by welding after considerable chipping.

(J) The walls of the by-pass valve were brought straight down to the casing to eliminate sharp changes in direction of section and permit better feeding. The outlet was cast separately and welded on.

In addition to the changes listed above, padding was provided to insure proper feeding. This extra metal was removed from the casting in the chipping and cleaning operation. These castings were cast flange-up in a manner similar to that mentioned previously. The castings were radiographed and were found to be exceptionally free from defects.

In this particular case the use of a model of the casting as originally designed not only resulted in changes in design which facilitated production, but it also reduced the cost of pattern construction considerably.

RADIOGRAPHY IN THE FOUNDRY.

If several castings are to be prepared from one pattern, radiographic tests become a distinct aid to the foundryman. In the case of the turbine castings mentioned above, one casting of each type was prepared and examined thoroughly before production was started on the remainder of the order. In this case, due to the changes in design, no changes were required. In the production of other castings, however, defects have been found in the first casting which were eliminated from all succeeding castings by slight changes in the pattern to facilitate directional solidification.

CHILLING OF STEEL CASTINGS.

Proper chilling is also an important factor in the production of sound castings. There still are sections of castings which it is impossible to feed and in these cases the foundryman's only expedient in the production of sound castings is the chill. There have been many arguments concerning the use of external and internal chills. The authors prefer the use of external chills for several reasons. The size of the chill employed is important when either external or internal chills are used, as the effect of the chill may prevent feeding if too large, and fail to accomplish anything if too small. With internal chills other factors arise. The chill must fuse into the cast matrix if a perfectly sound casting is to be obtained. The chill must be absolutely clean and dry if blow-holes or porous spots are to be eliminated. In green sand practice the chills can easily be inserted just prior to closing the mold and the cleanliness of the chill is comparatively easy to control. This is not always true in dry sand practice, for if the chills must be inserted into the green mold, the fumes from the organic binders leave a deposit on the chills when the mold is dried, which invariably causes trouble in the finished casting.

The effect of internal chills of various sizes upon cast sections was studied by the authors in a very simple experiment. Ordinary well-fed coupons with cross sections of 1 inch and 3 inches were molded in dry sand. After the molds were dried, chills 3/32, ⅛, ¼, ⅜, ½ and ⅝ inch in diameter, respectively, were inserted in the mold. These chills had previously been cleaned in an acid, then in a caustic bath, and nickel-plated to insure cleanliness. The molds were bottom-poured so that the steel would rise evenly over the entire chill.

This experiment, of course, indicates the effect of chills only upon metal that rises over the chill. A chill placed so that a large quantity of metal would run past it before the mold was filled, would have an entirely different effect upon the metal as the chill would heat up slowly and a portion of it might be eroded. In these circumstances a considerably larger chill would be required to accomplish the same purpose.

If the photomacrographs of the etched sections of some of these chilled coupons are examined, several interesting points may be

noted. The ⅝-inch diameter chill did not "fuse in" in either the 1-inch or 3-inch section. The mechanical bond in the 1-inch section was so poor that upon deep etching the acid penetrated the crack and enlarged it. (Figure 10.) It should also be noted that the chilled envelope that first formed on the chill cracked as the chill was heated and expanded. The dense chilled area extends across the entire section and therefore no feeding took place below the chill. A small secondary pipe may be seen about mid-way between the chill and the bottom of the casting. A radiograph of this section is shown on Plate 27.

The ⅝-inch chill placed in the 3-inch section (Figure 11) also failed to fuse in, but the mechanical bond was considerably better than that found in the 1-inch section. A slight crack was also formed in this case. The area of dense chilled material is about the same size as that found in the 1-inch section. In this case the chilled area is surrounded by a ring of porous dendritic material which is a semi-circular line similar to what is commonly called "axial weakness."

The ½-inch diameter chills also failed to fuse in properly in either section (Figure 9, Figure 13) and the effect, while slightly less in magnitude, is similar to that of the ⅝-inch chill.

The ⅜-inch rod was the largest chill that showed any indication of fusion with the cast material in the 3-inch section. The photomacrograph of this section is shown in Figure 12. In this case the chilled area is quite small. An indication of a small circumferential crack may be seen just above the chill. A photomacrograph of the fusion zone in this section is shown in Figure 15. The unfused chill-cast metal interface of the ½-inch chill in the 1-inch section (Figure 16) is also shown for comparison.

The ordinary horseshoe-nail chill cast into a 3-inch section is shown in Figure 14. In this case also the chill is welded to the cast material but, again, the chilling action has been slight, for the chilled area is very small. The large internal stresses brought about by chilling may be imagined by noting the diagonal cracks appearing in the head of the horseshoe nail. These cracks have, of course, been enlarged by the deep etching treatment, but they were visible in the rough-ground unetched specimen. Similar cracks are visible in the chills shown in Figures 9 and 19.

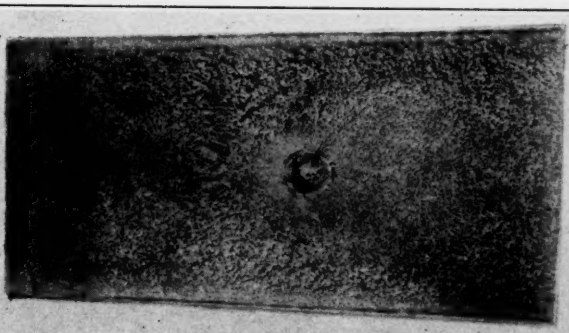


FIG. 9

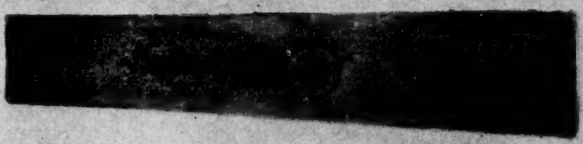


FIG. 10

FIG. 11

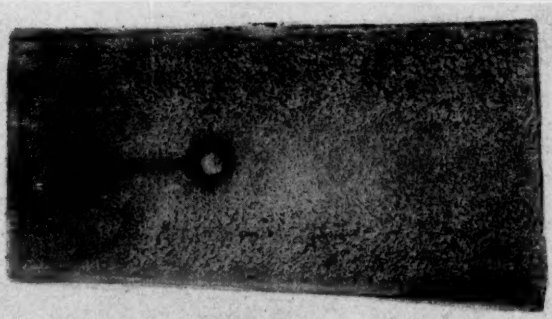


FIG. 12

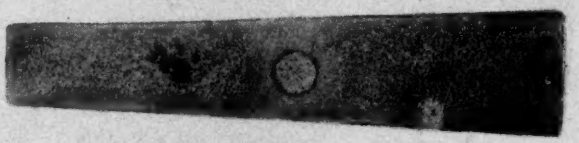
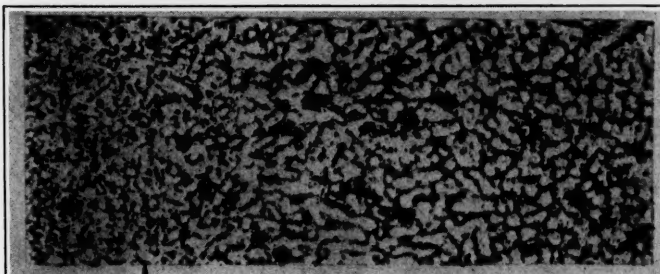


FIG. 13

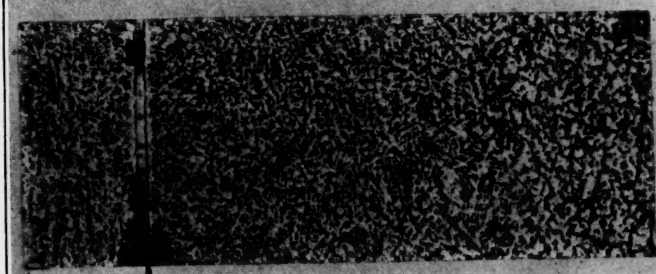
FIG. 14



CHILL-CAST METAL INTERFACE

FIG. 15

FUSION ZONE OF 3/8 INCH DIAMETER CHILL IN 3 INCH CAST STEEL SECTION .X25



CHILL-CAST METAL INTERFACE

FIG. 16

FUSION ZONE OF 1/2 INCH DIAMETER CHILL IN 1 INCH CAST STEEL SECTION

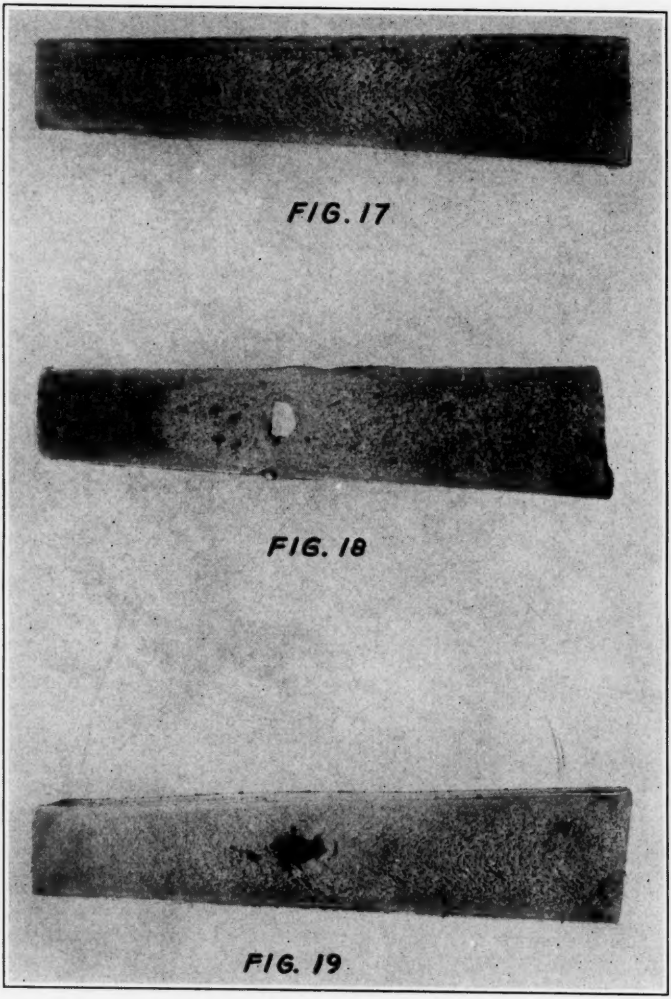


FIG. 17

FIG. 18

FIG. 19

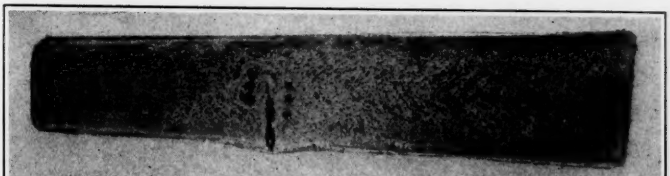


FIG. 20

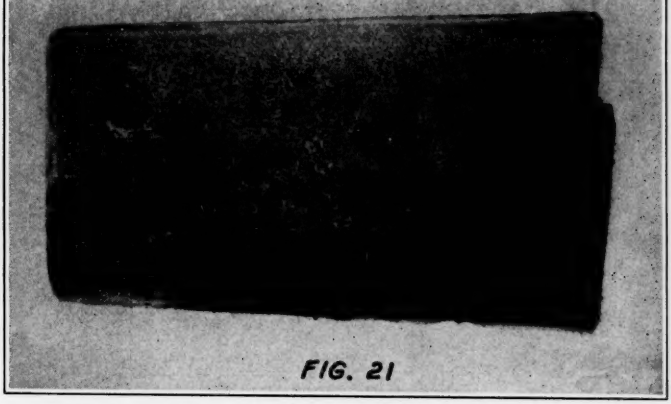
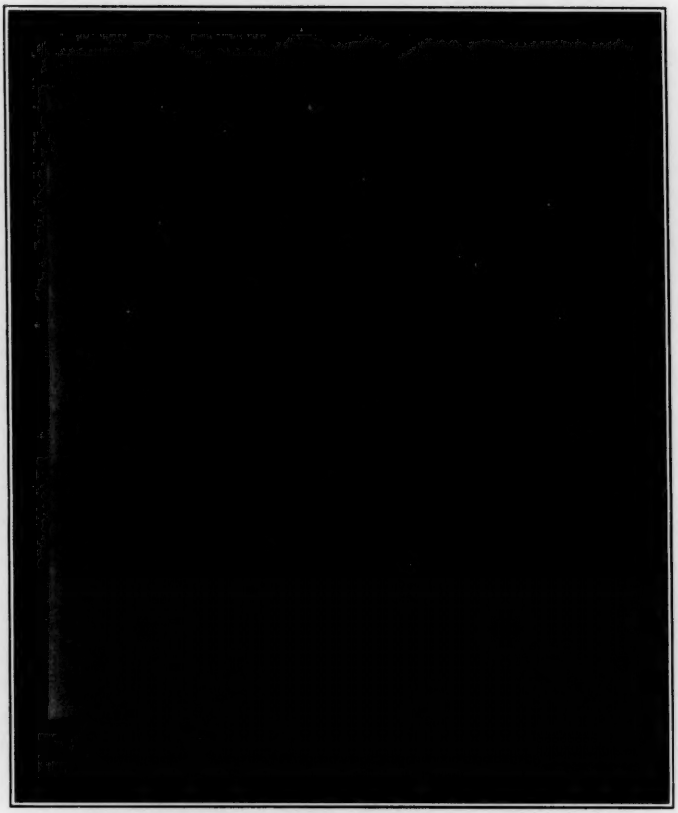


FIG. 21



RADIOGRAPH SHOWING POROUS AREA AND SECONDARY PIPE.

The ⅛-inch diameter rod was the largest chill that showed good fusion in the 1-inch cast section. The chilled area is also quite small in this case (Figure 17). The horseshoe nail did not fuse into the 1-inch section at all (Figure 18). The ¼-inch chill indicated partial fusion only (Figure 19). A porous area and a secondary pipe are visible below the chill in the etched section and also in the radiograph. (See opposite plate.)

The two sizes of coil chills used seemed to fuse in very well. The small coil (3/32-inch diameter wire) used in the 1-inch section chilled but a small area of metal. The outline of this chilled area is visible in the etched cross section of the casting (Figure 20). The chilled area produced by the larger coil chill in the 3-inch section is not as well defined. This section is shown in Figure 21. In spite of the precautions taken, this chill must have collected some dirt or water, as there are porous areas above as well as below the chill.

As the coupons containing these chills were available, test specimens were machined from them in such a manner that the chill passed through the center of the test specimen normal to the direction of testing. The data obtained on machined specimens of this type can not be correlated, for as the size of the chill increases, the area of cast metal present in the cross section of the specimen decreases rapidly. In the specimens containing the larger chills the central portion of the test bars was practically all "chill," whereas in other specimens very little chill metal was present. The only point worthy of note indicated by these data was the fact that, provided the chill was actually fused in, the mechanical properties were not seriously affected.

The advantages in favor of the use of external chills are: (1) that fusion between the chill and the casting is not important in considering the size of the chill, (2) cleanliness is not as important, as the gases evolved can escape through the sand, and (3) in many cases the chills can be used more than once. External chills have the disadvantage that for some applications they must be cast, or machined, to fit the surface they are to chill, and of course, have the same difficulty as internal chills in that the choice of the proper size is most important.

The effect of external chills of various sizes has been studied qualitatively in a few of the adjoining sections mentioned previ-

ously. It should be noted again that these sections have not been fed except through the arms and that, therefore, they are typical only of the inaccessible junctions found in actual castings. It will be noted that in the case of the T-section with unusually large radii, some of the cylindrical chills employed are not those that might be used in actual foundry practice. They were included in the study in order that a comparison of the results might be made with those obtained with the T-section having smaller radii. The other unusual shapes were used so that the effect of the amount of surface in contact with the casting might be noted.

The cross sectional area of the chill, the perimeter of the chill in contact with the casting (noted as the "effective perimeter"), and the cross sectional area of the defect are given in each case. This method of illustration was chosen, as it was deemed to be the easiest manner to visualize the effect of the chill upon the sections.

CHILLED L-SECTIONS.

The effect of chills upon the defects found in unfed L-sections is shown on page 224. A ½-inch diameter external chill placed at the radius of the inner corner reduces the size of the defect considerably. A chill 1 inch in diameter, or a small triangular chill with about the same cross sectional area, produced a sound section.

CHILLED T-SECTIONS.

It is difficult to produce sound T-sections by the use of external chills alone. Eight different sizes of chills were used on T-section 202 and while each type produced a smaller defect than that present in the original casting, only one of the modifications produced a sound casting. The types of chills used are shown on page 224, et al. Chills ½, 1, 1½, and 2 inches in diameter, respectively, were placed at the radii of the section. As the size of the chill at the radius was increased, the size of the defect decreased until a critical size of chill was reached.

The increase in chill diameter from 1½ to 2 inches also increased the size of the radius and this apparently counteracted the effect of the larger chill, as the size of the defect obtained is approximately the same in each case.

Two triangular chills were also used. The smaller of the two had a volume approximately equal to that of the 1-inch diameter chill with, of course, a much larger area in contact with the casting. This increase of the area in contact with the casting did not affect the size of the defect, as the result obtained with the 1-inch diameter is approximately the same as that obtained when the triangular chill is used.

It has been noted that chills placed at the radii of a T-section tend to move the defect toward the top of the T. A plate chill placed across the top of the T has the opposite effect. This type of chill will decrease the size of the defect and move the defect down into the leg of the T (202-7). If a combination of these two types of chills, i. e., 1-inch diameter chills at the radii plus a plate across the top, is used, it is possible to produce a sound section (202-8).

If the leg of the T is smaller than the top of the T, a plate chill across the top is in many cases all that is required to produce a sound junction (210-1).

In T-sections, excessive fillets are a liability to the foundryman, as it is very difficult to produce a sound section. This is illustrated by a series of studies with chills of various sizes with pattern 204. As in the T-section previously mentioned, an increase in the size of the chill tends to reduce the size of the defect. The size of the defect does not decrease as rapidly as in the previous case. Even a chill 4 inches in diameter does not reduce the defect to a size comparable to that obtained with a chill 2 inches in diameter in the T-section previously discussed.

When a very large chill that fits the entire radius is used (204-5), the defect, while of a different shape, is as large as that found in the casting made without chills. It was suggested by a foundryman who visited this Laboratory that the defect shown in this section was much larger than one could expect and he mentioned the possibility that radiography had introduced considerable error. This casting was, therefore, sectioned on the center line and the defect revealed was compared with the original radiograph. The outlines of the defect on the radiograph and on the casting coincided perfectly. Calculations on the amount of liquid steel involved in producing a defect of this size have indicated that with such a large chill it is theoretically possible to have a defect even larger than that found.

Table VII

Casting Number	Corner Radius in Inches	Types of Chills Used	Inches Effective Perimeter	Total Cross-Sectional Area in Square Inches	Area of Defect in Sq.In.
L Sections					
102	0.50	None	-	-	2.8
102-1	0.50	1/2-inch diameter	0.25	0.20	0.1
102-2	0.50	1-inch diameter	0.78	0.78	None
102-3	0.50	Small triangle	1.87	0.70	None
T Sections					
202	0.50	None	-	-	3.6
202-1	0.50	1/2-inch diameter	0.50	0.40	2.1
202-2	0.50	1-inch diameter	1.56	1.56	0.8
202-3	0.75	1-1/2 inch diameter	2.36	3.54	0.3
202-4	1.00	2-inch diameter	3.14	6.28	0.4
202-5	0.50	Small triangles	3.74	1.40	0.9
202-6	0.50	Large triangles	7.60	5.38	0.5
202-7	0.50	1-inch plate	4.00	3.75	0.6
202-8	0.50	1-inch diameter plus 1-inch plate	5.56	5.31	None
204	3.00	None	-	-	4.1
204-1	3.00	1-inch diameter	0.25	1.56	3.0
204-2	3.00	1-1/2 inch diameter	0.38	3.54	2.7
204-3	3.00	2-inch diameter	0.50	6.28	1.3
204-4	3.00	3-inch diameter	1.0	7.07	1.1
204-5	3.00	Semi-circular (3-inch radius)	9.42	28.27	4.1
204-6	3.00	3-inch diameter plus plate	5.00	10.82	0.2
I Sections					
502	0.50	None	-	-	6.4
502-1	0.50	1/2-inch diameter	1.00	0.80	2.1
502-2	0.50	1-inch diameter	3.12	3.12	0.6
502-3	0.50	Small triangles	7.48	2.80	0.7
502-4	0.50	Large triangles	15.2	10.76	0.2
502-5	0.50	1-inch plates	3.12	15.57	0.5
503-1	1.00	2-inch diameter	6.28	12.56	0.9
506	0.50	None	-	-	5.0
506-1	0.50	1-inch diameter	3.12	3.12	1.2
T Sections					
402	-	None	-	-	2.7
402-1	-	1- 1-inch diameter	0.78	0.78	2.1
402-2	-	3- 1-inch diameter	2.34	2.34	1.6
402-3	-	1-inch diameter plus 2-inch diameter	3.92	7.06	1.0
402-4	-	1-inch diameter plus chill plates	9.05	8.78	0.2
402-5	-	1-inch plates	9.05	11.89	0.1

The minimum defect in this type of T-section was obtained when 4-inch diameter chills were used at the radii and a plate chill was placed across the top of the T.

The X-sections were the most difficult sections to chill properly. In fact, it was not possible to produce a sound X-section by chilling alone. An increase in the size of the chill again produced a smaller defect. The best results were obtained with the large triangular chill (502-4). An increase in the radii at the corners of the casting, as in the case of the T-section (202-4), produced a larger, rather than a smaller defect (503-1). In this case it appears that the ½-inch radius is preferable to the 1-inch radius.

The staggered X-section, unfed and unchilled, presents an elongated defect. Chilling this section with 1-inch diameter bars divides the defect into two smaller defects. Using chills larger in diameter increases, rather than decreases, the size of the defects produced. It would seem, therefore, as suggested in the section on design, that staggered section with some distance between the arms would be preferred (see 509, 510, 511, 512). These sections could be chilled as T-sections and produced without defects if feeding was not possible.

Sections in the form of a Y are not encountered as frequently as some of the other types. They are, like the X-sections, very difficult to produce without defects unless they can be fed directly. The results of various chilling methods are shown on pages 229 and 230. The test result obtained is indicated in casting 402-5.

A summary of the effect of external chills upon the sections studied is presented in Table VII. It is interesting to note that in the castings studied the diameter of the chill was very important when an increase in this diameter meant an increase in the radius at the corner of the casting. For instance, in the T-section 202 a radius of approximately ¾ of an inch appears to be the critical radius. An increase from a 1-inch diameter chill (½-inch radius) to a 1½-inch diameter chill (¾-inch radius) decreased the cross sectional area of the defect from 0.8 to 0.3 square inches. If, however, the diameter of the chill is increased to 2 inches (1-inch radius) the cross sectional area of the defect becomes 0.4 square inches. The same thing may be noted with the X-section. In this case an increase in the diameter of the chill from 1 inch to 2 inches

increases the cross sectional area of the defect from 0.6 to 0.9 square inches.

Another interesting fact is that the location of the chill is as important as the size of the chill. For instance, casting 202-6 is chilled with two triangular chills having a total cross sectional area of 5.38 square inches and a total effective perimeter of 7.6 inches. The defect obtained has a cross sectional area of 0.5 square inches. Casting 202-8, however, is sound, and total cross sectional area and effective perimeter of the chills are 5.31 square inches and 5.56 inches, respectively.

The effective perimeter and the cross sectional area of the chill both govern the chilling effect of a particular chill, but the latter is the more important. The heat conductivity of steel is great enough so that the cross sectional area must be quite large in proportion to the effective perimeter before the efficiency of the chill is impaired. This is illustrated by results obtained on castings 202-2, 202-5, 502-2, 502-3, 502-5, 402-4, and 402-5. It will be noted that in each case where the 1-inch diameter chill and the small triangular chill are used the size of the defect is approximately the same, even though the effective perimeter of the triangular chill is over twice that of the 1-inch diameter chill. However, when the plate chill with a ½-inch radius is substituted for the 1-inch diameter chill, the cross sectional area is increased considerably, while the effective perimeter remains the same. The change in the size of the defect is very slight, indicating that plate chills of this type are very inefficient and not a great deal better than a 1-inch diameter bar.

Internal chills were used in an attempt to produce sound sections in cases where external chills could not do so. These attempts were not satisfactory, as in most cases the location of the chill was shown clearly on the radiograph by lack of fusion, dirt, or gas around the chill. Typical radiographs showing the type of defects encountered are shown on Plates 28 and 29. It should be noted that the type of defect is the same whether one coil chill or four are used, so that "over-chilling" can not be responsible. A longitudinal view of two coil chills is shown on Plate 30. In this case practically every turn of the coils may be seen. The use of solid internal chills presented the same difficulties and it appeared that, for the same volume of chilling material, as good results could be obtained with solid chills as with the coil variety.

It is the opinion of the authors that if chills similar to those mentioned above are used on sections less than 3 inches in thickness, the results would be similar. The effect of these chills upon defects present, of course, will increase as the size of the section decreases.

SUMMARY OF PART II.

The first requirement in the production of a sound casting is a design to which the principles of "controlled directional solidification" may be applied. If this is not possible with the design as originally produced, a few slight changes may be required. Models of the original design at a suitable scale are very helpful to both the designer and foundryman, as the changes required can then be pointed out. These models are sometimes a distinct aid in convincing the designer or consumer that the alterations desired are reasonable and not injurious to the proper use of the casting.

After the foundryman has obtained a workable design he can use the tools at his command, such as tapered sections, proper gating and heading, chills, relieving blocks, etc., to preclude the possibility of shrinkage cavities and hot tears. These foundry arts have been used to advantage on poorly designed castings, but they can not be expected to cure all the evils found in designs produced with little or no thought to foundry problems.

BIBLIOGRAPHY.

1. White, Clark, and Crocker, Am. Soc. of Mechanical Engineers, Vol. 58, November, 1936.

2. Lorig and Williams, Am. Foundrymen's Association—American Society for Testing Materials, "Symposium on Steel Castings," 1932.

3. Batty, G., Trans. Am. Foundrymen's Association, Vol. 6, p. 237, February, 1935.

4. Heuvers, A., Stahle und Eisen, 1929, No. 35.

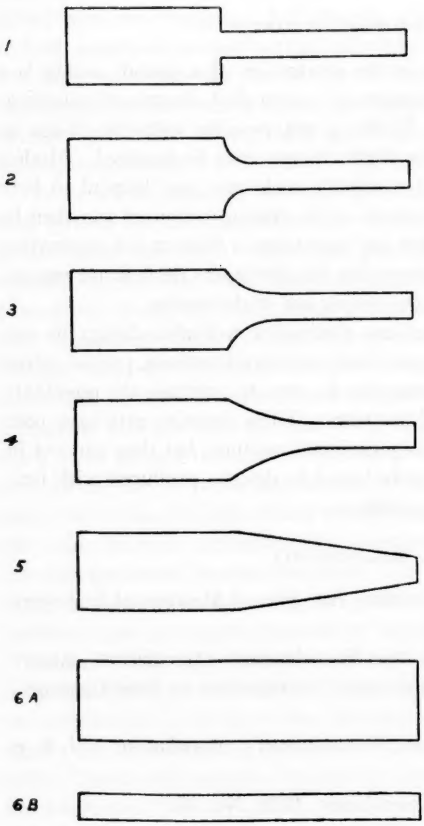
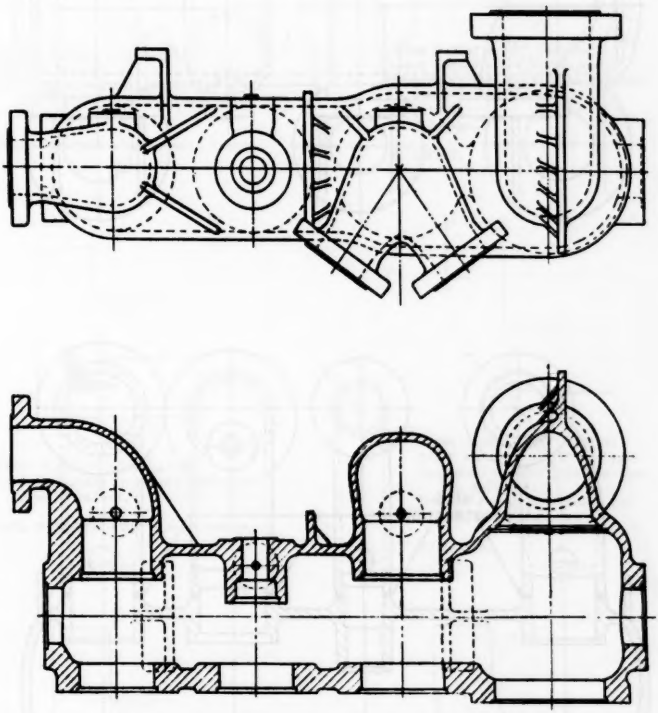
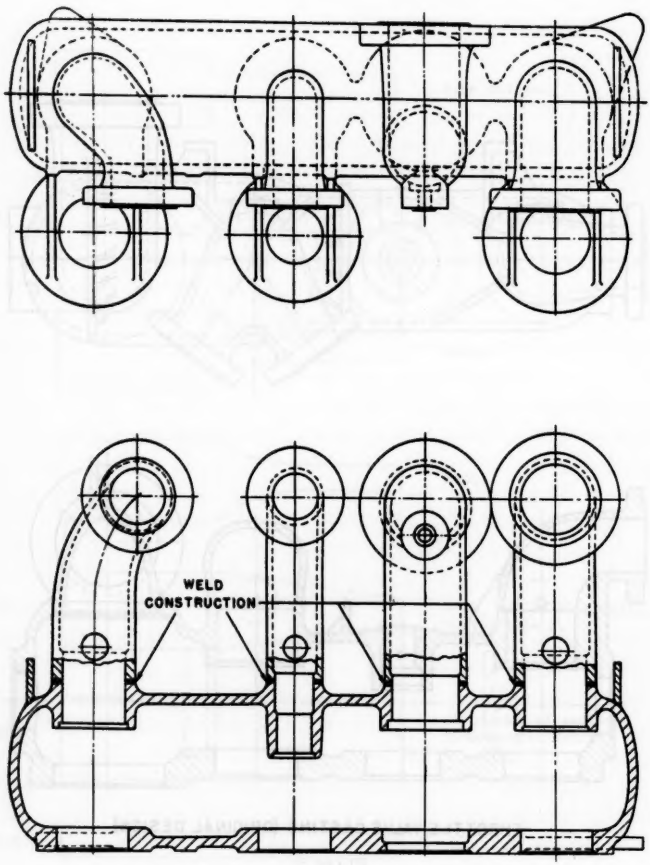

1
Poor design.
2
Not recommended.
3
Fair.
4
Good.
5
Best, and in some cases, better than 6.
6 A
No change of section. Recommended design.
6 B
No change of section. Recommended design.

PLATE 1.



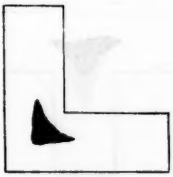
THROTTLE VALVE CASTING-(ORIGINAL DESIGN)

PLATE 2.



THROTTLE VALVE-(CAST WELDED CONSTRUCTION)

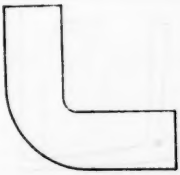
PLATE 3.



101

Square corners - no radii.
Section 3" x 3".
Poor design - also possibility of hot tears at sharp corner junction.

AREA OF DEFECT - 2.05 square inches.



104

Inner corner - 1/2" radius.
Outer corner - 4-1/2" radius.
Section at the junction is slightly smaller than the arms.
No defect.
Best design.

NO DEFECT.

102

Inner corner - 1/2" radius.
Radius slightly increases the size of defect.

AREA OF DEFECT - 2.8 square inches.

105

Inner corner - 1/2" radius.
Outer corner - 5-1/2" radius.
Very much smaller junction than arm sections.
Drastic design not needed for complete soundness.

NO DEFECT.

103

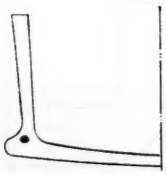
Inner corner - 1/2" radius.
Outer corner - 3-1/2" radius.
Uniform section shows a small defect.
Design better than 102.

AREA OF DEFECT - 0.6 square inches.

106

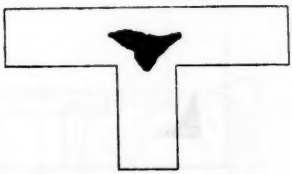
Inner corner - 3" radius.
Outer corner - 6" radius.
Uniform section with large radius - development of center line weakness which can be remedied by foundryman.
Good design.

PLATE 4.



107

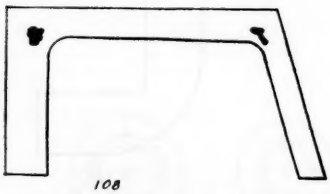
Section of a 14" Bitt casting.
Defective - a poor design.
To remedy -
Maintain uniform section or core out hole at position of defect.



201

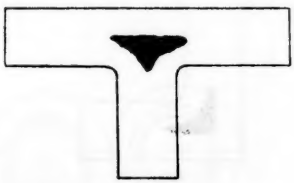
Section 3" x 3".
Square corners - no radii.
Very poor design.

AREA OF DEFECT - 3.5 square inches.



108

Double "L" from stern post casting.
Defective - poor design.
To remedy -
Eliminate corners.

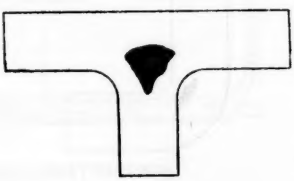


202

Inner corners - 1/2" radii.
AREA OF DEFECT - 3.6 square inches.

109

Double "L" from stern post casting.
Poor design.
Study also sections X and Y.
To remedy -
Make sections uniform and core out hot spot center.

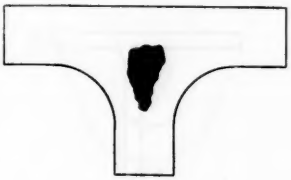


203

Inner corners - 1-1/2" radii.
Defect slightly larger than 202.

AREA OF DEFECT - 3.8 square inches.

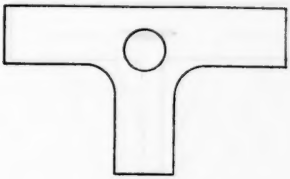
PLATE 5.



204

Inner corners - 3" radii.

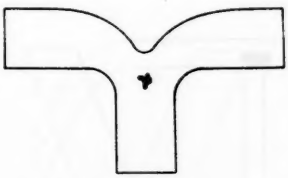
AREA OF DEFECT - 4.1 square inches.



207

Inner corners - 1-1/2" radii.
Cored 2" diameter hole.

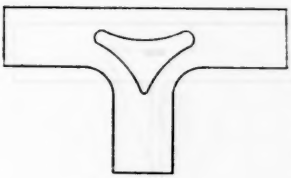
No defect.
The best design.



205

Inner corners - 1-1/2" radii.
Outside - 5" radius - V-shaped.
Design much better than 203.

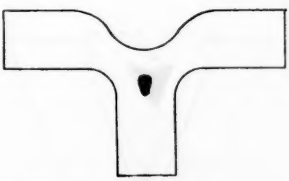
AREA OF DEFECT - 0.3 square inches.



208

Inner corners - 1-1/2" radii.
Cored hole.

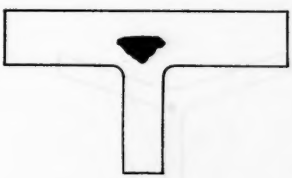
No defect.
Design not as practical as 207.



206

Inner corners - 1-1/2" radii.
Outside - 2" radius - U-shaped.
Defect larger than 205.

AREA OF DEFECT - 0.6 square inches.



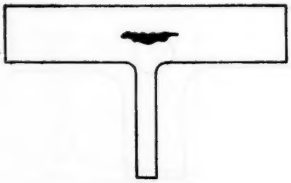
209

Sections: Arms - 3" x 3"
Leg - 2" x 3"

Inner corners - 1/2" radii.
Compare with 202.

AREA OF DEFECT - 1.8 square inches.

PLATE 6.

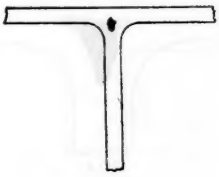


210

Sections: Arms - 3" x 3"
Leg - 1" x 3"

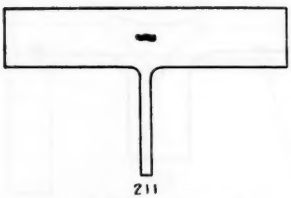
Inner corners - 1/2" radii.

AREA OF DEFECT - 1.0 square inches.



213

Section from a structural casting.
Remedy same as 212.

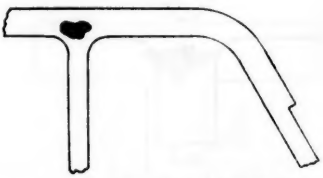


211

Sections: Arms - 3" x 3"
Leg - 1/2" x 3"

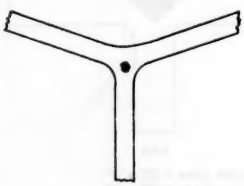
Inner corners - 1/2" radii.

AREA OF DEFECT - 0.2 square inches.



214

Section from a stem casting
To reduce size of defect use
dip in arm at intersection
as 205.



212

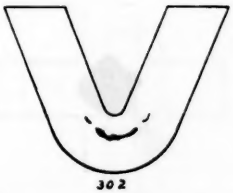
Section of an upper stem casting.
Use cored hole in design to
illiminate defect.

301

Members intersect at 45 degrees.
Section - 3" x 3".
No radii - sharp corners.

AREA OF DEFECT - 3.3 square inches.

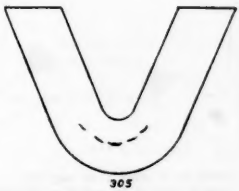
PLATE 7.



302

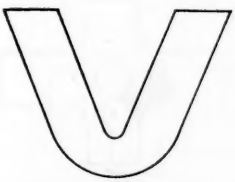
Inner radius - 1/2 inch.
Outer radius - 3-1/2 inches.
Uniform section.
Defect due to poor conduction of sand from the inner face.

AREA OF DEFECT - 0.3 square inches.



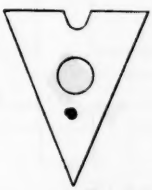
305

Inner radius - 1 inch.
Outer radius - 4 inches.
Uniform section - compare with 302.



303

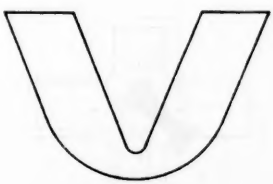
Inner radius - 1/2 inch.
Outer radius - 4 inches.
No defect.
Best design.



306

Inner radius - 1/2 inch.
Cored 2-inch diameter hole.

AREA OF DEFECT - 0.3 square inch.



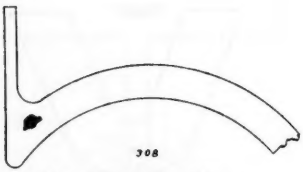
304

Inner radius - 1/2 inch.
Outer radius - 4-1/2 inches.
No defect.
Design not as good as 303.

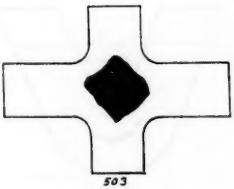
307

Portion of lower stem casting.
Section could not be fed except through the arms.
Design very poor.

PLATE 8.



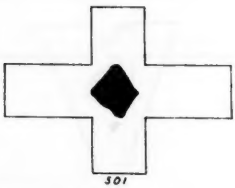
Portion of stem post casting.
Design should be modified to take off the lower portion of the "V".



All radii 1 inch.

Defect slightly larger than 503.

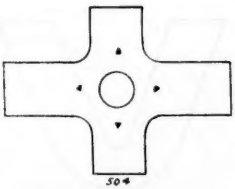
AREA OF DEFECT - 8.1 square inches.



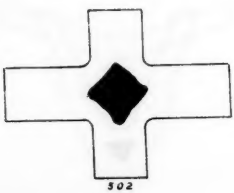
Section 3" x 3".

Sharp corners - no radii.

AREA OF DEFECT - 5.5 square inches.



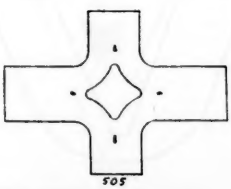
All radii 1 inch.
Two-inch diameter cored hole.
Four very small cavities at the head of each arm.



All radii 1/2 inch.

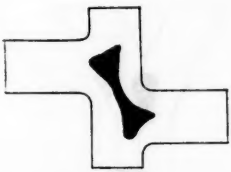
Defect slightly larger than 502.

AREA OF DEFECT - 6.4 square inches.



All radii 1 inch.
Cored rectangular hole cavities smaller than those of 504.

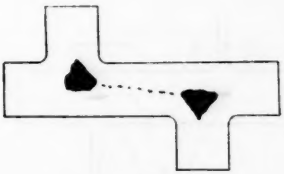
PLATE 9.



506

All radii 1/2 inch.
One arm completely offset.
Area of defect about the same as 502.

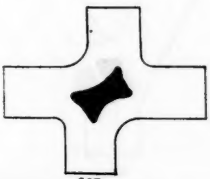
AREA OF DEFECT - 5.5 square inches.



509

All sections 3" x 3".
All radii 1/2 inch.
Center lines of offsets are
8 inches apart.

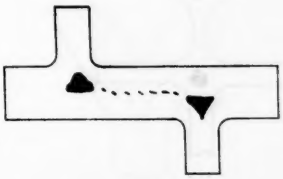
TOTAL AREA OF DEFECTS - 4.3 square inches.



507

Two radii 1/2 inch.
Two radii 1-1/2 inches.
One arm 1/2 offset.

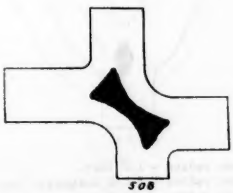
AREA OF DEFECT - 5.3 square inches.



510

Offset sections 2" x 3".
All radii 1/2 inch.

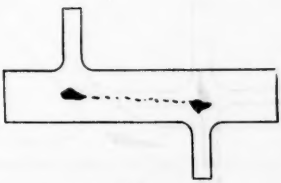
TOTAL AREA OF DEFECTS - 2.0 square inches.



508

Two radii 1/2 inch.
Two radii 1-1/2 inches.
Both arms 1/2 offset.

AREA OF DEFECT - 5.9 square inches.

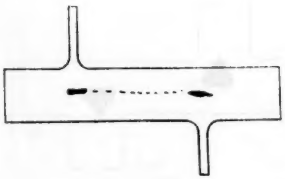


511

Offset sections 1" x 3".
All radii 1/2 inch.

TOTAL AREA OF DEFECTS - 0.9 square inches.

PLATE 10.



512

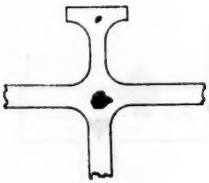
Offset sections 1/2" x 3".
All radii 1/2 inch.

TOTAL AREA OF DEFECTS - 0.4 square inch.

401

Members intersect at an angle of 60 degrees.
Section - 3" x 3".
Sharp corners - no radii.

AREA OF DEFECT - 2.7 square inches.



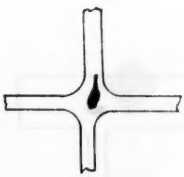
513

Section taken from a stern post casting.

402

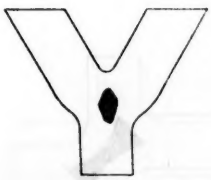
Standard section

AREA OF DEFECT - 2.7 square inches.



514

Showing defect found in a portion of a structural casting with arm offset.



403

Inner radius - 1/2 inch.
Outer radius - 3-1/2 inches.
Lower radii - 1 inch.
Defect smaller than 401, 402.

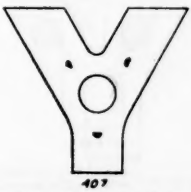
AREA OF DEFECT - 1.9 square inches.

PLATE 11.

404

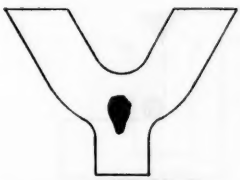
Inner radius - 3 inches.
Outer radius - 6 inches.
Lower radii - 1 inch.
Defect similar to 403.

AREA OF DEFECT - 1.9 square inches.



407

Same as 402, except with cored hole 2 inches in diameter.



405

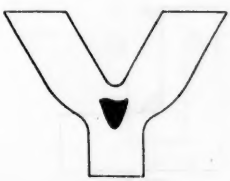
Inner radius - 1-1/2 inches.
Outer radius - 4-1/2 inches.
Lower radii - 1 inch.
Defect the same size as 403.

AREA OF DEFECT - 1.9 square inches.

408

Same as 402, except with cored triangular hole.

NO DEFECT.



406

Inner radius - 1/2 inch.
Outer radius - 4-1/2 inches.
Lower radii - 1 inch.
Defect nearly the same size as 403.

AREA OF DEFECT - 1.8 square inches.

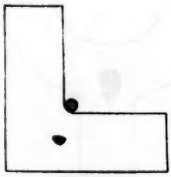
409

Portion from the upper stem structural casting showing type of defect found.

PLATE 12.

410

Section of the lower stem casting showing double "T" and type of defect encountered.



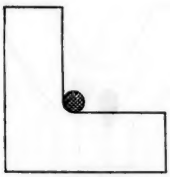
102-1

1/2" diameter chill.
Cross-sectional area - 0.20 square inches.
Effective perimeter - 0.25 inches.

AREA OF DEFECT - 0.1 square inches

411

Section of a structural casting showing type of defect found.



102-2

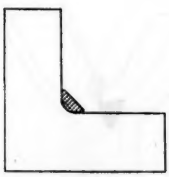
One inch diameter chill.
Cross-sectional area - 0.78 square inches.
Effective perimeter - 0.78 inches.

NO DEFECT.

102

Standard section.

AREA OF DEFECT - 2.8 square inches.

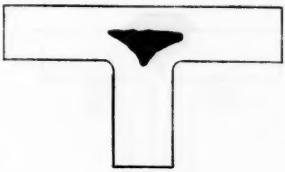


102-3

Small triangular chill.
Cross-sectional area - 0.70 square inches.
Effective perimeter - 1.87 inches.

NO DEFECT.

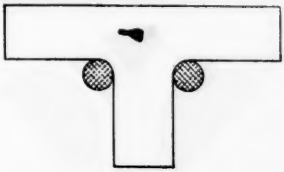
PLATE 13.



202

Standard section.

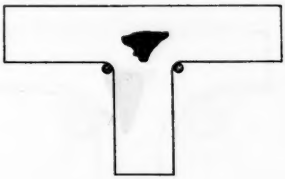
AREA OF DEFECT - 3.6 square inches.



202-3

1-1/2" diameter chills.
Total cross-sectional area - 3.54 square inches.
Total effective perimeter - 2.36 inches.

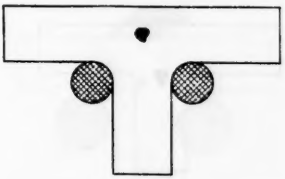
AREA OF DEFECT - 0.3 square inches.



202-1

1/2-inch diameter chills.
Total cross-sectional area - 0.40 square inches.
Total effective perimeter - 0.50 inches.

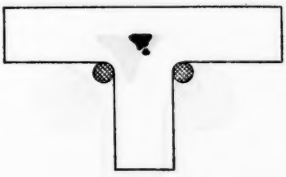
AREA OF DEFECT - 2.1 square inches.



202-4

2-inch diameter chills.
Total cross-sectional area - 6.28 square inches.
Total effective perimeter - 3.14 inches.

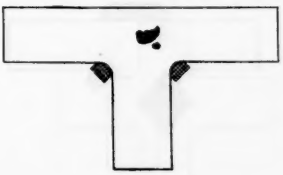
AREA OF DEFECT - 0.4 square inches.



202-2

1-inch diameter chills.
Total cross-sectional area - 1.56 square inches.
Total effective perimeter - 1.56 inches.

AREA OF DEFECT - 0.8 square inches.

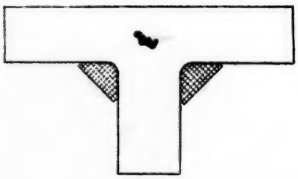


202-5

Small triangular chills.
Total cross-sectional area - 0.70 square inches.
Total effective perimeter - 1.87 inches.

AREA OF DEFECT - 0.9 square inches.

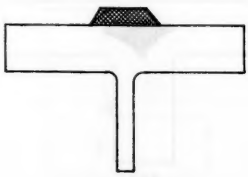
PLATE 14.



202-6

Large triangular chill.
Total cross-sectional area - 5.38 square inches.
Total effective perimeter - 7.6 inches.

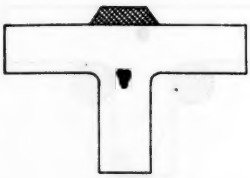
AREA OF DEFECT - 0.5 square inches.



210-1

1" Plate chill (4" to 2-1/2").
Cross-sectional area - 3.75 square inches.
Effective perimeter - 4.0 inches.

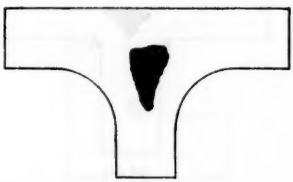
NO DEFECT.



202-7

1" Plate chill (4" to 2-1/2").
Cross-sectional area - 3.75 square inches.
Effective perimeter - 4.0 inches.

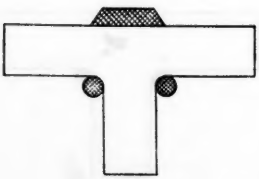
AREA OF DEFECT - 0.6 square inches.



204

Standard section.

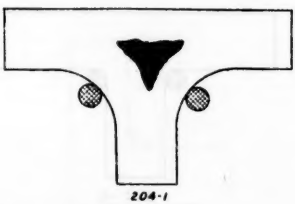
AREA OF DEFECT - 4.1 square inches.



202-8

1" Diameter chills plus 1" plate chill.
Total cross-sectional area - 5.31 square inches.
Total effective perimeter - 5.56 inches.

NO DEFECT.

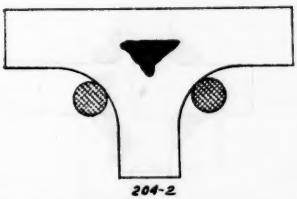


204-1

1-inch Diameter chills.
Total cross-sectional area - 1.56 square inches.
Total effective perimeter - 0.25 inches.

AREA OF DEFECT - 3.9 square inches.

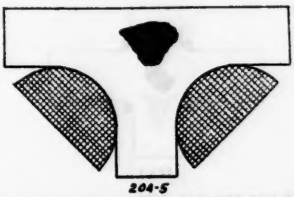
PLATE 15.



204-2

1-1/2 inch Diameter chills.
Total cross-sectional area - 3.54 square inches.
Total effective perimeter - 0.38 inches.

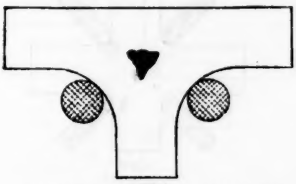
AREA OF DEFECT - 2.7 square inches.



204-5

Semi-circular chill (3" radius).
Total cross-sectional area - 28.27 square inches.
Total effective perimeter - 9.42 inches.

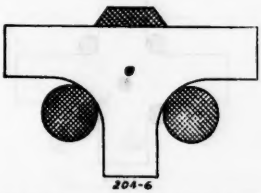
AREA OF DEFECT - 4.1 square inches.



204-3

2-inch Diameter chills.
Total cross-sectional area - 6.28 square inches.
Total effective perimeter - 0.50 inches.

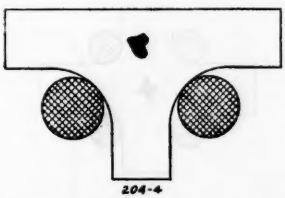
AREA OF DEFECT - 1.3 square inches.



204-6

3-inch Diameter chills plus 1-inch plate chill.
Total cross-sectional area - 10.82 square inches.
Total effective perimeter - 5.0 inches.

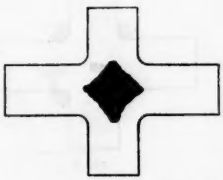
AREA OF DEFECT - 0.20 square inches.



204-4

3-inch Diameter chills.
Total cross-sectional area - 7.07 square inches.
Total effective perimeter - 1.0 inches.

AREA OF DEFECT - 1.1 square inches.

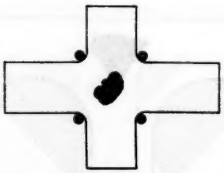


502

Standard section.

AREA OF DEFECT - 6.4 square inches.

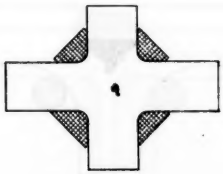
PLATE 16.



502-1

1/2-inch Diameter chill.
Total cross-sectional area - 0.80 square inches.
Total effective perimeter - 1.00 inches.

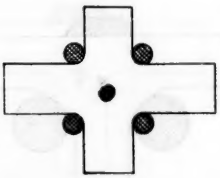
AREA OF DEFECT - 2.1 square inches.



502-4

Large triangular chills.
Total cross-sectional area - 10.76 square inches.
Total effective perimeter - 15.2 inches.

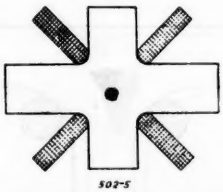
AREA OF DEFECT - 0.2 square inches.



502-2

1-inch Diameter chills.
Total cross-sectional area - 3.12 square inches.
Total effective perimeter - 3.12 inches.

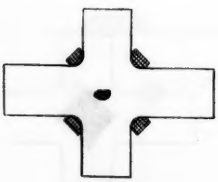
AREA OF DEFECT - 0.60 square inches.



502-5

Plate chills (1" x 4" - 1/2" radius).
Total cross-sectional area - 15.57 square inches.
Total effective perimeter - 3.12 inches.

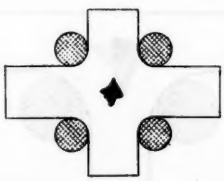
AREA OF DEFECT - 0.5 square inch.



502-3

Small triangular chills.
Total cross-sectional area - 2.80 square inches.
Total effective perimeter - 7.48 inches.

AREA OF DEFECT - 0.7 square inches

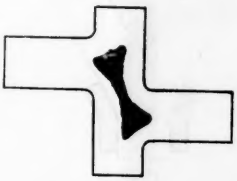


503-1

2-inch Diameter chills.
Total cross-sectional area - 12.56 square inches.
Total effective perimeter - 6.28 inches.

AREA OF DEFECT - 0.9 square inch.

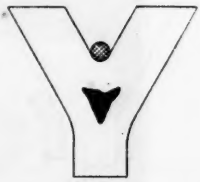
PLATE 17.



506

Standard section.

AREA OF DEFECT - 5.0 square inches.



402-1

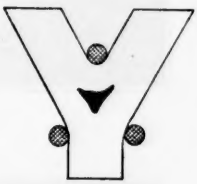
1-inch Diameter chill.
Cross-sectional area - 0.78 square inches.
Effective perimeter - 0.78 inches.

AREA OF DEFECT - 2.1 square inches.

506-1

1-inch Diameter chills.
Total cross-sectional area - 3.12 square inches.
Total effective perimeter - 3.12 inches.

AREA OF DEFECT - 1.2 square inches.



402-2

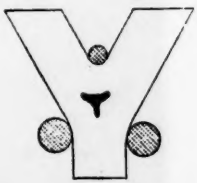
1-inch Diameter chills.
Total cross-sectional area - 2.34 square inches.
Total effective perimeter - 2.34 inches.

AREA OF DEFECT - 1.6 suare inches.

402

Inner radius - 1/2 inch.
Outer radii - 3 inches.

AREA OF DEFECT - 2.7 square inches.

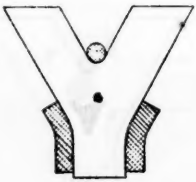


402-3

1-inch Diameter chill plus 2-inch diameter chills.
Total cross-sectional area - 7.06 square inches.
Total effective perimeter - 3.92 inches.

AREA OF DEFECT - 1.0 square inches.

PLATE 18.



402-4

1-inch Diameter chill plus 1-inch chill plates.
Total cross-sectional area - 8.78 square inches.
Total effective perimeter - 9.05 inches.

AREA OF DEFECT - 0.2 square inches.

402-5

1-inch Chill plates.
Total cross-sectional area - 11.89 square inches.
Total effective perimeter - 9.05 inches.

AREA OF DEFECT - 0.1 square inches.

PLATE 19.

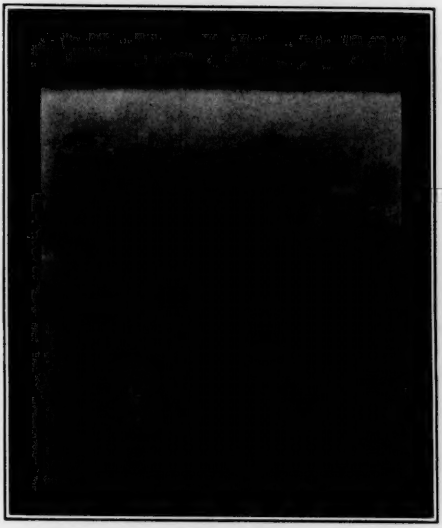


PLATE 20.

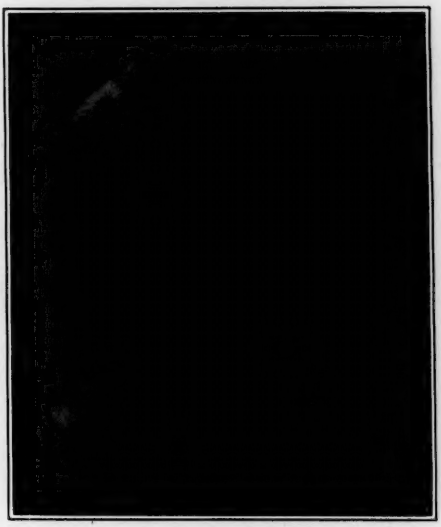


PLATE 21.

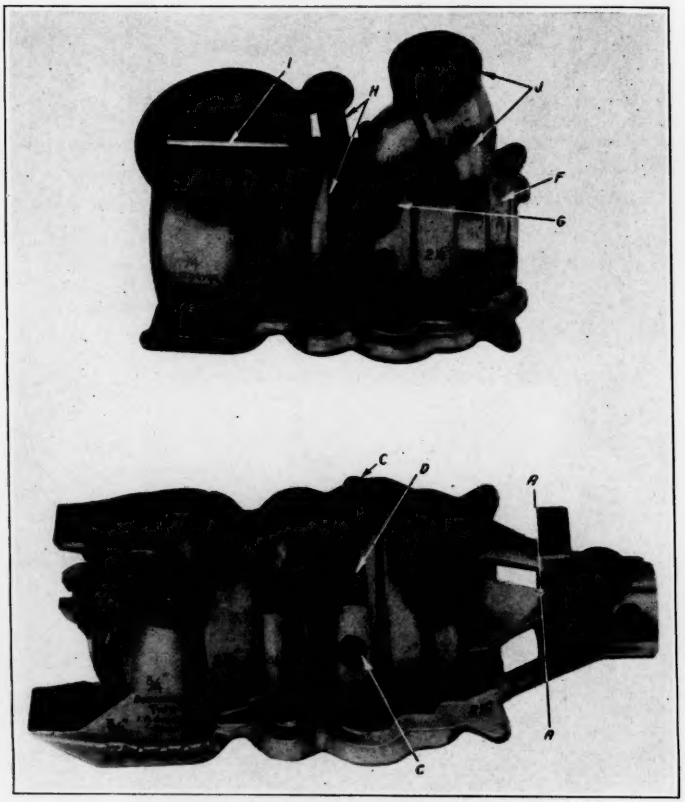


PLATE 22.

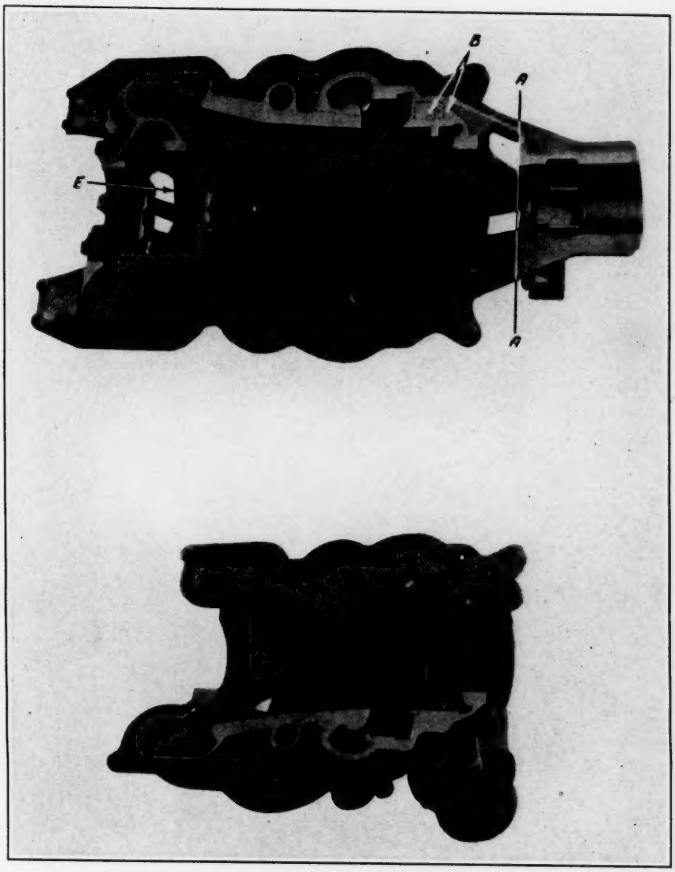


PLATE 23.

PLATE 24.

PLATE 25.

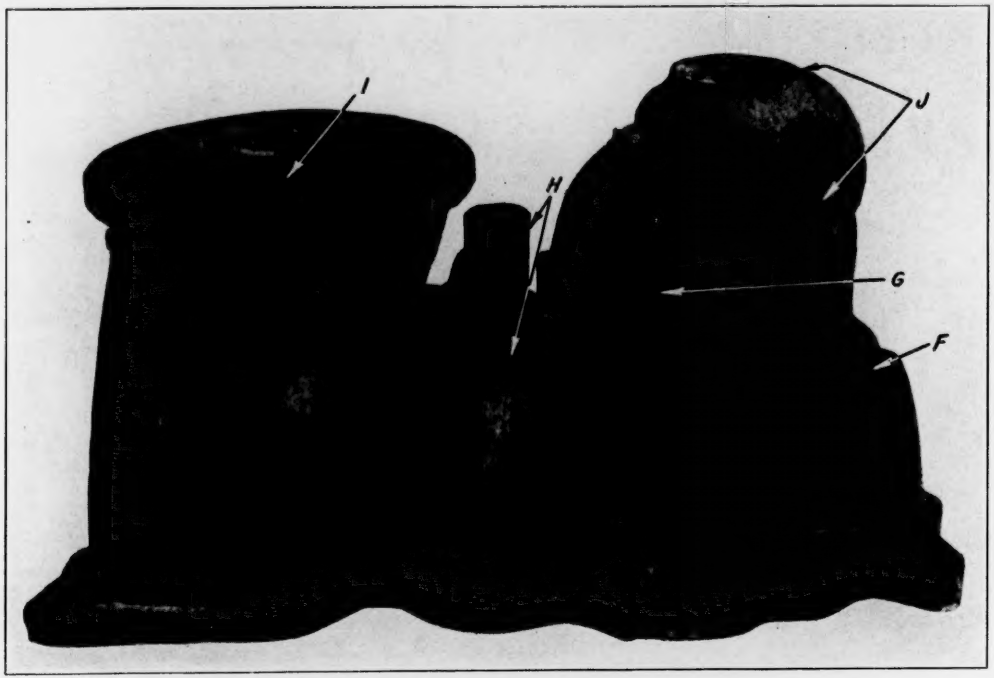


PLATE 25.

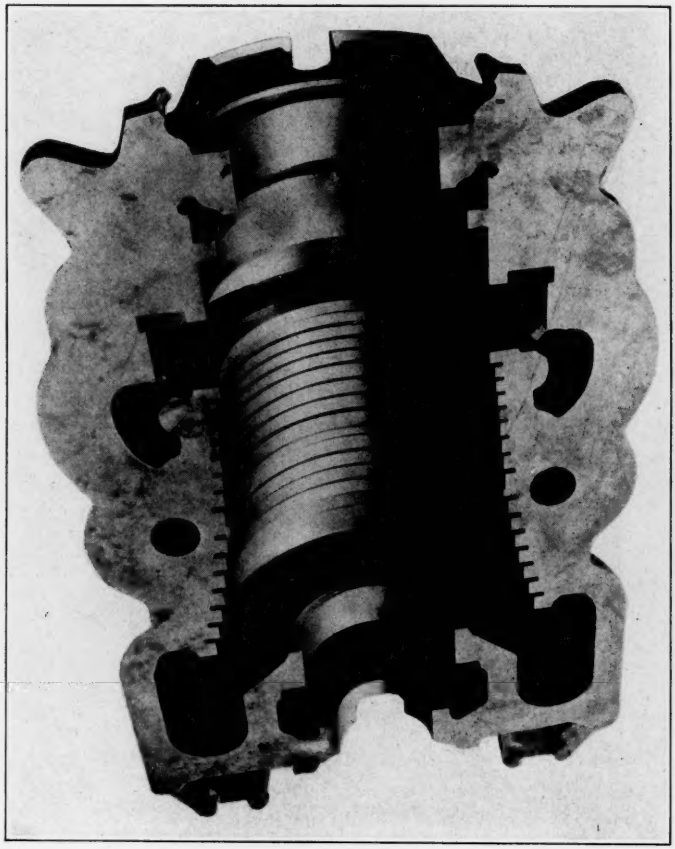


PLATE 26.

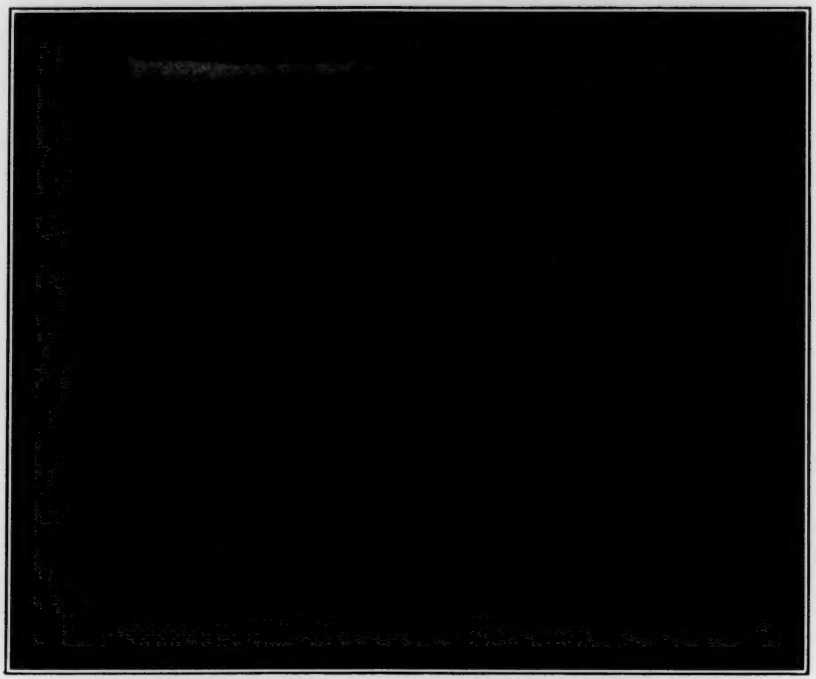


PLATE 27.

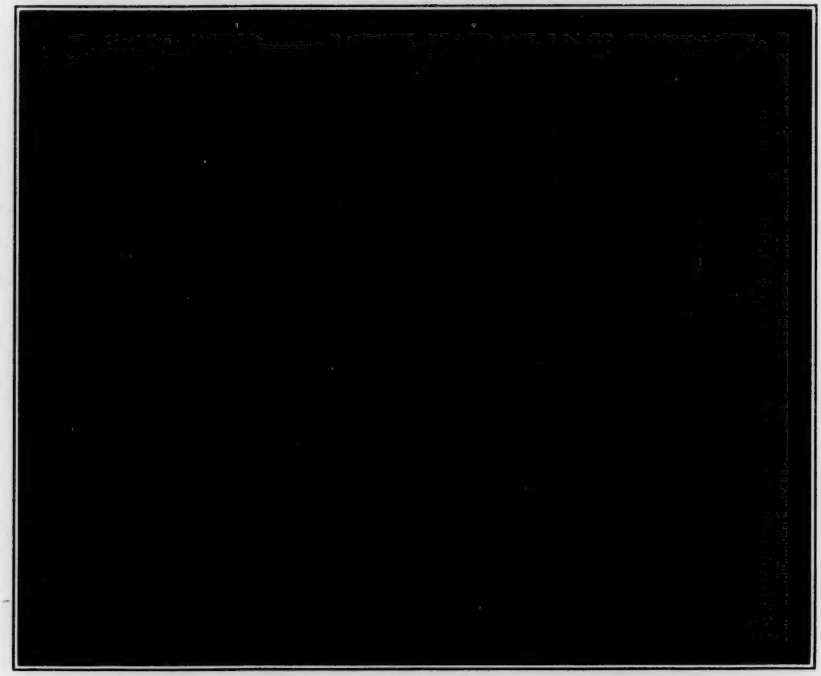


PLATE 28.

PLATE 29.

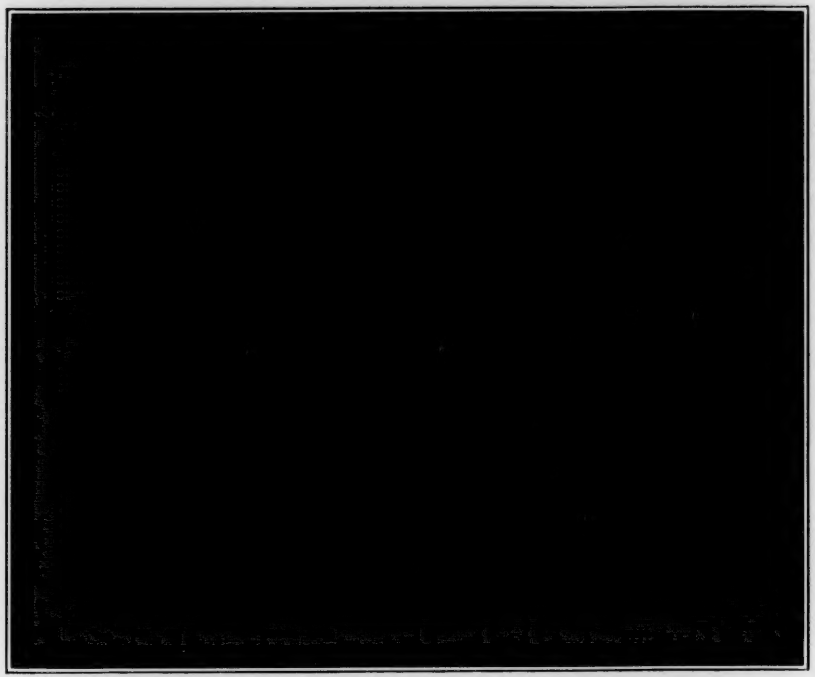


PLATE 29.

PLATE 30.

THE EFFECTS OF TURBULENCE AND CAVITATION UPON EROSION AND CORROSION.

By Commander (E) C. J. Odend'hal, U. S. Coast Guard, Member *.

The serious effect of high water velocity and of the oxidation due to entrained air present in liquid flow, and the equally deleterious effect of electrolytic action when dissimilar metals form the container for liquid flow, are well known, and both have been widely studied as separate phenomena. It has remained for the author to present a highly plausible theory to account for the interaction of the two attack mechanisms as they affect salt water lines, condenser circulating systems, and boiler feed systems. If his theory is sound, and it should readily yield to demonstration, it suggests obvious methods for combatting the damaging effect wherever it may appear. At a time when scoop design, injections and discharges, and condenser arrangements are all under such close scrutiny, Commander Odend'hal's discussion should prove to be of particular interest.

The erosive effect of a river on its bank increases as the fourth power of the velocity. The same principle would apply if the bank were made of brass, copper or steel instead of clay or sand. Naturally, however, the life of a metal bank would be longer than a bank made of some softer material if the impingement of the stream were the only factor to be considered. Unfortunately, another factor plays an important part, and while the usefulness of a bank may be prolonged as far as impingement is concerned if made of metal, nevertheless, a metal bank would not be as capable of withstanding the ravages of oxidation to such a degree as a clay bank, and would deteriorate far more rapidly.

Material has been gradually improved through the ages to withstand better the wearing action of water. Troughs were first used

* Headquarters, U. S. Coast Guard, Treasury Department, Washington, D. C.

which approximated the river bed, but were inadequate when pressures and velocities were raised, necessitating replacement by pipes to confine the stream. Velocities were originally very low, which had no apparent eroding action, and the haphazard mixing of ingredients produced a pipe well able to conduct the water indefinitely. As velocities increased, a different condition existed, which obliged the scientifically inclined to try other mixtures capable of holding up for a longer period of time. If impact were the only problem associated with higher velocities, it has been solved by the metallurgists whose excellent work has resulted in materials well able to withstand any action of this nature.

Though as stated, the erosive effect of velocity increases as the fourth power, the harmful action of some other factor associated with higher speeds, later discovered to be air liberation, increases out of all proportion. Air not only causes corrosion by contact, but results in erosion of metal by impact, and the continuance of eletrolytic action by the removal of inhibitors. As is well known, the size of a unit decreases as the velocity of its operating medium increases. The ability involved in approaching the ideal machine is not proportional to the ingenuity required in allaying the harmful effects to metals resulting from such an improvement.

A few basic principles may be used as a foundation upon which to further a study of erosion and corrosion.

a. The saturation of air in water depends upon the pressure and temperature of the liquid. More air is absorbed the higher the pressure and the lower the temperature.

b. Electrolysis is proportional to the instability of metals in an electrolyte, and to the removal of inhibitors from the anode and cathode. The greater the tendency of a metal to enter solution the greater will be the electrolytic action, but if the film formed as a result of the reaction is allowed to remain on the metals, corrosion will decrease.

The principle outlined under (*a*) indicates that there is a "critical" temperature and pressure governing the amount of air contained in water under a saturated condition. Either lowering the pressure or raising the temperature will free air until equilibrium is again restored. Pressure and velocity of a stream of water are closely associated, and the lowering or raising of velocity will result

in a rise or fall of pressure. Hence, the quantity of air in water at any one instant depends upon temperature, and the correlation of velocity and pressure. Pressure, velocity, and temperature variations occur during the transit of water from the sea through a pump for sanitary or other purposes.

In the case of a sanitary pump, the story is as follows: Sea water contains a definite amount of air at a certain temperature and at atmospheric pressure. The temperature is raised slightly and the pressure lowered in the passage of water to the impeller. Air is naturally liberated. If there are bends or obstructions in the injection pipe an increased effect will be produced with a release of the air held in suspension.

As stated, the air content of water is governed by the pressure and temperature of the liquid, but paradoxical as it may seem, more air is contained in sea water at the surface where the pressure is less than at a depth approximating the draft of a vessel. This is brought about by the stirring of the surface as the ship progresses resulting in a more intimate contact of water and air, with a consequent increase in the capacity for absorption. The above explanation is made to show that the location of the injection valve has a direct bearing on the initial contents of air, and hence on corrosion.

Most of the air is entrained in the water until it reaches the pump chamber when a portion is released. This is apparent from an inspection of the material constituting the circulator ensemble, which indicates that corrosion primarily starts at the pump, very little damage having occurred in the suction line.

It is natural that the liberation of air should be most pronounced in the unit responsible to the greatest extent for the initial starting of and continuance of flow. This unit to perform its function is dependent upon the rotation of vanes, thereby subjecting its constituent parts to wide variations of pressure. The greatest variation occurs where cavitation is introduced. As the name implies, gaps or holes are formed on certain parts of the impeller vanes, caused by the inability of the water to follow the contour of the vanes due to their design and speed. Pressures in the areas where cavitation exists are reduced, and as they are below the critical, air and water vapor are released. A portion of the air adheres to the metallic walls in small globules which collapse and disappear as if absorbed

by the vanes. Another portion of air and water vapor oscillate in the water near the origin of formation, and appear to be reabsorbed in the liquid after bombarding the metallic walls. The air in the first instance results in direct oxidation, and the air and water vapor in the second causes erosion.

It is questionable whether cavitation can be entirely eliminated, but from the progress made in the design of propellers, influenced by the experiments conducted in the field of aviation, it is reasonable to predict that harmful results from this source will eventually be inconsequential.

Even at the present time, existing equipment without modification, can be made to give far longer useful service. As globules of air by collapsing damage the surface to which they cling, it is evident that their retention until released from their envelopes depends upon the roughness of the metal or its ability to hold the air for a sufficient length of time. This naturally suggests a smooth surface or one free of any film of foreign material. It might not appear practical to subject pumps to frequent dismantling for the purpose of burnishing irregular surfaces, or to polish metal with no apparent blemish, yet this procedure is worth while.

Though the discussion so far has under consideration the case of a sanitary system, it might not be inopportune to emphasize the necessity for absolutely clean, burnished surfaces in other systems. A condenser tube is a case in point. In some instances an attempt to polish up the interior of a conductor would be an absurdity, but in others the effort expended might be advisable.

In a superficial manner, the action of the stream of water from the injection to the pump has been considered. The same applies as regards the discharge from the pump. Discharge lines are usually of great strength, embodying numerous bends, valves, and fittings. In addition, due to the line traversing heated quarters, the effect of temperature is more pronounced. Every obstruction in the line produces turbulence and cavitation and is associated with variations in pressure. A study of sanitary pipes, which have failed after a comparatively short length of service, has demonstrated that corrosion and erosion have occurred at bends or in the vicinity of hindrances causing turbulence. Any small irregularity in a pipe acts as an obstruction, which compels the stream of water to be

diverted from its course and results in a pocket of low pressure to be formed on the far side. This small deflector may be a portion of brazing adhering to the surface or even a small quantity of scale. The results are magnified if the obstruction is of any size and of such a shape as to change the direction of the stream abruptly.

Following the course of the stream after discharge from the pump, the picture of events is clearly visualized. A manifold is first encountered with consequent turbulence before the flow is straightened out to take its prescribed channel. In the vicinity of the manifold, iron sections become spongy, and brass parts are gouged. Later, after leaving the manifold, a sharp bend is encountered, and the stream on the outer periphery of the bend is flattened out, causing an increase in velocity, drop in pressure, and release of a portion of air. If the temperature has been increased during this transit, an additional amount of air is left behind at the elbow. Further increase in temperature as well as drop in pressure as the stream proceeds to the next hindrance results in the globules of air released and held in suspension, being in a state of readiness to perform their work of destruction wherever the opportunity permits, which will be in the neighborhood of the next projection no matter how small. And so to the destination of the stream.

As noted under (*b*), another factor which causes corrosion is electrolysis. It would be a waste of time to dwell in detail upon the fundamentals of a subject so well known, but to mention one phase of the phenomenon might not be amiss, which phase is the effect of air on the continuance of the action.

Assuming that the sanitary system is composed of dissimilar metals such as copper piping, bronze impeller, cast iron pump body, brass flanges, composition valves, etc., through which flows salt water containing acids and nitrogen products, it is apparent that sections form a number of comparatively active cells. Smaller cells exist in areas where through strain or deposits the metal is not potentially uniform. In each cell electrolysis occurs. The anode enters into solution displacing the hydrogen from the electrolyte or salt water, which is deposited on the cathode. However, the hydrogen which forms on the negative electrode slows up the reaction and hinders further dissolution of the anode. The action is similar to closing down on a valve in a pipe line. If the hydrogen film is

not removed, the anodic reaction will stop and further corrosion will be prevented. Naturally such a film cannot withstand the impact of a stream of water, and even if able to adhere under this bombardment, it may react with oxygen if air were present in the water. Globules of air in the vicinity of the cathode causes in addition an impact with the surface which removes a portion of the hydrogen film not affected by chemical action. If there is sufficient air present to completely remove the film and directly attack the metal, electrolysis, corrosion, and erosion will result.

As implied, electrolysis depends upon the potential of the metals, the constituents of the electrolyte, and the quantity of the air present. The first factor is greatly magnified by building a system of widely different materials; the second is hastened by the acid condition of the electrolyte resulting from factory refuse, sewerage, etc., and from the breakdown of magnesium chloride into a chemical union of hydrogen and chlorine; and the third as has been shown depends upon the construction of the system influencing the liberation of air. Eliminating one without considering the other two is similar to purchasing a carriage for transportation without at the same time buying a horse and a complete harnessing equipment.

Let us consider what might be done to render air in a sanitary system less harmful, assuming electrolysis has been eliminated to a degree by building the plant of potentially equal materials.

a. Eliminate sharp bends and obstructions in the suction and discharge lines. Valves should be straight through flow to avoid turbulence.

b. Pump should be designed for minimum turbulence and cavitation, and should be operated at the designed speed and at the rated capacity as far as practical.

c. Long discharge lines should be avoided. Instead of one large sanitary pump for all purposes, there should be a number widely distributed. One or several pumps would then perform work confined to the engine room, another set to duty in the boiler room, and additional pumps, preferably motor driven, to assignments in other sections of the vessel. Each pump should be installed near the work involved.

d. Suction and discharge lines should be equipped at intervals along the length with air eliminators to free the system at each

point occasioned by a decrease of pressure and increase of temperature. Without such eliminators, it is evident that the sanitary line should increase in size as it continues. The practicability of this is open to question. An increase of area along the length of the pipe may be productive in maintaining the pressure above the critical at all times.

Although the remarks made concerning a sanitary system are applicable to the conditions governing the condenser equipment, there are a few points which may be worth considering in regards to the latter.

As in the case of the sanitary system, corrosion practically starts at the pump. Here, however, the havoc raised is not so pronounced for the reason that the pressure differences are not as great. Up to this point of flow no great damage has been done, and none will occur until the water enters the condenser chest. Here the direction of flow is usually at right angles to the layout of condenser tubes. An ideal setting for turbulence exists. Air attacks the heads, tube sheet and tubes, and as these elements are made up of dissimilar metals, produces a most pronounced effect in maintaining electrolysis active. Like a great number of individuals attempting to enter one gate at the same time, water and entrained air try to crowd each other into the restricted tube passage, resulting in air being dissipated at the mouth during the struggle. Additional globules of air which have been liberated are entrained in the stream, and are carried along in suspension until due to an increase in temperature, drop in pressure, and an obstruction in the path, a number drop out and proceed to carry on their work of destruction.

Continuing this depressing story would be productive of no results, and the finish is left to the imagination. It is more important that an attempt should be made to introduce a yarn having a more cheerful ending. In this connection, the following is presented:

a. The cross sectional area of the stream of water should increase gradually from the injection valve to the overboard discharge.

b. The flow of water entering the chest should be in the direction of the tubes with no irregular or oversize chest intervening between the pump and tubes.

c. Tubes should be smaller in diameter at one end than at the other to carry out the idea of gradually enlarged areas. All tubes

may be of the same size, but the number of tubes in the second pass should be increased. Conically shaped tubes will not be popularly received, however, and this innovation is presented as a solution which was arrived at through the above line of reasoning.

d. Tube sheets, tubes and heads should be of the same material. If heads are of different material, they and the bolts securing them should be covered with an insulating compound, securely bonded to insure no electrical contact whatsoever with other parts of the condenser. Material of tubes in my opinion is not the culprit as is believed by many. The whole affair hinges on the factors mentioned in the foregoing discussion.

Consideration has been given to two specified systems, but the same applies to any other cooling installation; the effects of course being governed by the operating condition and perfection of design. While not classed in the category of a cooling layout, the feed combination presents a similar state of affairs.

In this instance, the condenser acts as a deaerator. Here a portion of air is released, and is expelled to atmosphere by means of the air ejector. Air however is not entirely eliminated from the condensate in the condenser. In addition to the air remaining, the condensate absorbs air on its way to the feed and filter tank from leaking valves and stuffing boxes, and also absorbs air upon its expulsion into the tank. In the old feed installations, the condensate was delivered through an opening at the top of the feed tank, and sheets of water were passed through filtering compartments arranged in series. Naturally, great quantities of air were absorbed. In later installations, when feed tanks form part of the unit, the discharge is below the water line. As velocity of flow in the tank is relatively slow, sufficient time is allowed even in the later design for the water to absorb air. To preclude any trouble from this source, closed feed systems without the interposition of open tanks is advocated and adopted to a great extent. Also, a means of removing air at some point between the condenser and feed pump suction forms part of a number of equipments.

Assuming that all of the air has not been removed from the feed prior to its arrival at the heater, an attempt is made to get rid of this element there by providing air vents. Even though the temperature of the water is raised going through the heater, the pressure is in-

creased to above boiler pressure, so the effect of one nearly counteracts the effect of the other as far as liberation of air is concerned.

To free the feed of its entire supply of air would necessitate heating and agitating the water in its passage through the feed heater until a temperature corresponding to its pressure is reached. A number of deaerating heaters are used at the present time for this purpose. However, in some instances, no such povision is made, and the boiler unavoidably accomplishes the same results.

Often times, the feed is discharged into the steam drum vertically, and strikes an umbrella-shaped bell above the outlet which causes an abrupt reversal of flow. The stream is thereby broken up into small particles, introducing a condition where heat is readily absorbed, and air consequently freed. This results in considerable corrosion over the interior surface of the steam drum in the neighborhood of the bell mentioned. Even at this stage of the cycle, air may not have been entirely removed, and the last trace is liberated in the headers and tubes as the water continues on its course from the steam drum.

Providing the design makes no provision for entirely deaerating the water just prior to the entrance of feed into the boiler, there should be some unit installed at this point as a last safeguard. Substituting a trap, the water in which is in contact with steam, to replace the inlet elbow and umbrella bell mentioned with provisions for freeing the air to atmosphere through a thermostatic valve similar to a radiator valve would be productive of worthwhile results.

The above discussion could be interminably prolonged by amplification without in any way adding to what has already been said. For this reason the case is closed, and is offered for consideration.

FIFTY YEARS OF NAVAL ENGINEERING IN RETROSPECT.

PART II.

1898-1908.

By Herbert M. Neuhaus, Member.*

The American Society of Naval Engineers having arrived at the half-century mark of its existence reaches back through the rich years of experience to re-illuminate engineering developments engendered during that interval. A brief historical exposition of the Society's formation in October, 1888, has been presented in the February, 1938, Journal *and with it a historical sketch of marine and Naval engineering from 1888 to 1898. Highlights of that period include the change from compound engines to triple expansion engines, establishment of the water-tube boiler in the World's navies, the use of steel forgings for engine structures and highly-stressed moving parts, use of steel piping, and marked the entry of the steam turbine as a competitor for the reciprocating steam engine.*

Editor's Note: Mr. Edwin B. Sadtler, and some others, have called our attention to an error which was made in Part I, on Page 5 of the February, 1938, issue of the Journal. *In the paragraph at the top of the page, it is stated that the Atlanta, Boston, Chicago, and Dolphin were appropriated for in 1883, but that actual construction on them did not start until 1886. This is not correct, for the vessels' keels were laid in the Roach Ship Yard in 1883, and the Atlanta was commissioned in 1886. Mr. Sadtler graduated from the University of Pennsylvania in 1883, and immediately went to work in the Roach Ship Yard so that he was sure that his memory was not at fault though he was not able to corroborate his belief. The Society is pleased to do so. The error was inadvertent and was caught in late proof, but not before the article had been sent to press.*

* Associate Mechanical Engineer, Design Division, Bureau of Engineering.

Passing of the War with Spain left the United States an empire with far-flung frontiers girdling half of the globe and separated by thousands of watery miles. The Hawaiian Islands now became by treaty a part of this country, certain islands in the Caribbean were deeded over—in short, we had become a World power. New problems arose with these distant possessions, Naval strategy taking on a new aspect for this nation, and with it, engineer's headaches. New vessels became necessary; vessels of great cruising radius to compensate for a lack of bases, vessels of great stamina and reliability to permit long intervals between Navy Yard overhauls, vessels that were self-sustaining to the last degree. The improvements and developments of the preceding ten years continued their accelerated pace with change becoming the watchword.

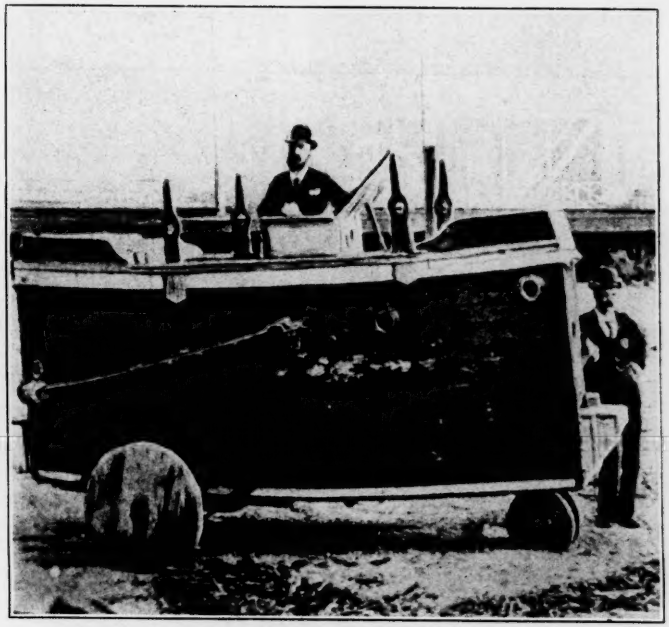
Our "New Navy," but sixteen years from its inception, had its baptism of fire on two fronts, the "eastern" in Cuba, the "western" at Manila. Both locations involved theaters of operation distant from bases and far from the nearest Navy Yard. Both battles were dependent upon the individual efficiencies of their component ships, not the least of which included their motive power or engineering plant.

Let us examine the makeup of Dewey's fleet at the Battle of Manila on May first of 1898. At the outbreak of the War the American ships were located at Hong Kong, the President's order then received making the Philippine Islands the theater of operations and the Spanish squadron there the immediate objective. A heterogeneous collection comprised the American Fleet though the Spanish unit was no better. Of American ships we find the *Olympia, Boston, Baltimore,* two purchased colliers, the unprotected revenue cutter *Hugh McCullogh, Raleigh,* and *Concord.* It appears that while entrance of the channel to Manila Bay was being forced, it became the unhappy lot of the engineers to give away the attacking forces by a flare-up from the overheated smokepipes of the *McCullogh.* The remaining story of the Battle is known to all, the loss of one man comprising the total casualties. Why was this victory so readily won? The question is easy to answer for it is found in the efficiency of all *personnel.* Had not the ships been kept in fighting trim and in ace-high mechanical condition and well-supplied with fuel, the victory would not have been so easy. Dewey

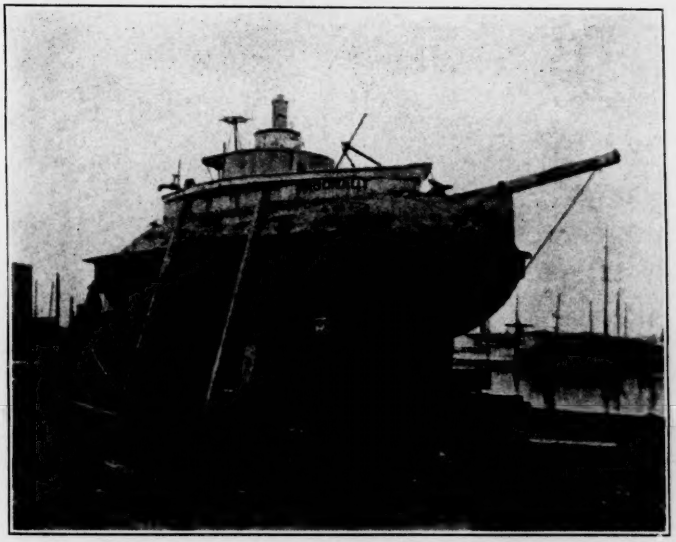
was operating thousands of miles away from his home bases; he was left to independent action, and in carrying out his mission he realized the strategical value of well-kept ships.

Let the picture shift now to the western hemisphere where another battle has taken place. It is regrettable that the JOURNAL does not carry more than a casual mention of the Battle of Manila, though it does carry the story of Santiago in full, particularly the outstanding performer, the *Oregon,* whose trip from Bremerton to the battle zone is one unequalled in the records of our history. The destruction of the Spanish forces under Admiral Cervera was complete, though the experiences of our Naval engineers afloat served to answer several questions relative to engineering construction that had, until then, been in doubt.

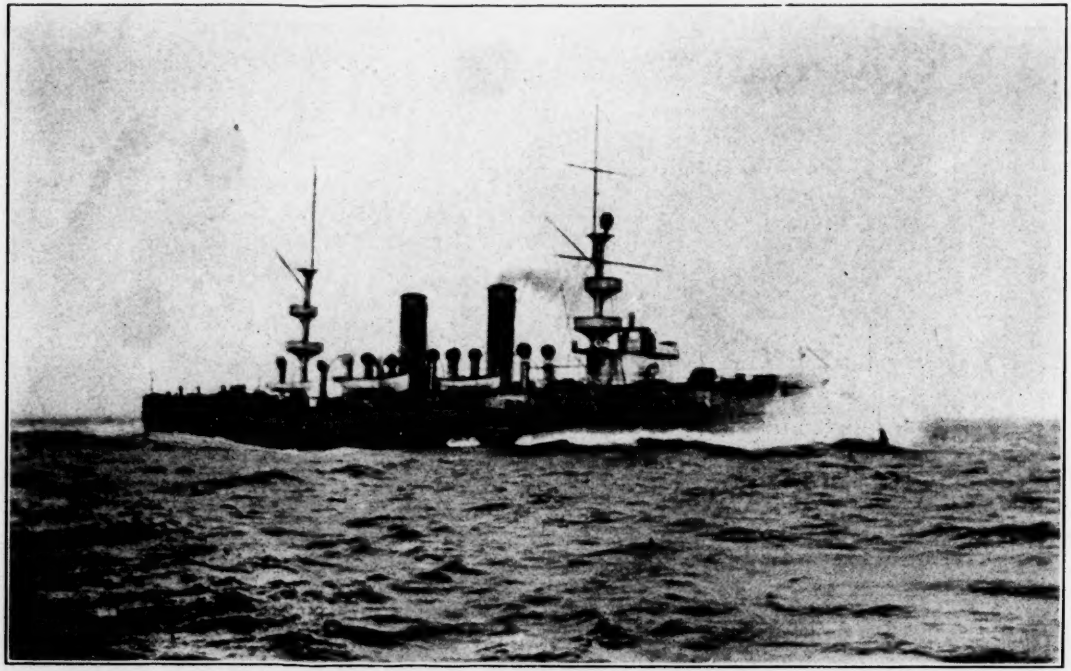
Weeks of operations in the Caribbean required constant care on the part of engineers, particularly the "bottling-up" of the Spanish in Santiago Bay. Battleships and smaller ships alike were required to keep their boilers clean, their engines in condition, and their fuel supply up while awaiting the "last dash" to sea in hot pursuit. Because of the long interval between the detection of the Spanish at Santiago and their subsequent hasty departure, crews of all vessels were kept busy cleaning engines, taking down boilers, and making routine repairs. A considerable amount of such effort was necessary for the nearest base was at Key West, which served only for smaller vessels. Large ships such as the *Texas* and *Iowa* were forced to proceed to Norfolk for drydocking, thereby losing several valuable days in transit. When the final supreme effort came, the *New York* and *Brooklyn* were found with their forward engines uncoupled and no time to connect them up. Other vessels were found in a similar state with one or more boilers down for overhaul, or their fires heavily banked. All started in pursuit of the enemy, though he, with his head start and all steam up, rapidly drew to the westward. As each pursuing ship built up its fires and brought more boilers on the line, the distance gradually closed, successive Spanish vessels being driven ashore in flames except the *Colon,* which appeared fair to escape. However, the *Brooklyn* kept up her dogged pace and the *Oregon* which had a position near the eastern end of the watching circle gradually pulled up to and passed every vessel ahead of her except the *Brooklyn.* The *Oregon's* six-



"Argonaut, Junior."



"Argonaut the First."
Figure 1.



U. S. S. "ALBANY."—FULL SPEED.
FIGURE 2.

teen and one-half knots that day equalled her trial record and her opening thirteen-inch salvo ranged ahead of the *Colon,* causing the latter to turn and head for the shore.

Readiness of the *Oregon* for the chase was the result of a strict engineering discipline and a conscientious attention to duty by her chief engineer, later Admiral Milligan. On her trip around South America every effort was made to keep her machinery in trim and when at the end of a 15,000-mile cruise she reported ready for duty without any attention necessary from a Navy Yard, the value of a definite engineering program was shown. The opening of the chase found the *Oregon* with fires and steam on all boilers, which served her in good stead. A brief of the *Oregon's* famous trip is again repeated in the paragraphs that follow.

On January 4th, 1898, the *Oregon,* attached to the Pacific Station, was docked at the Naval Station, Puget Sound. Her hull and bottom having been cleaned and painted and found in good condition, she was floated on February sixteenth. On March sixth, her engines were reported ready by the chief engineer, and at 6:50 A. M. the engines were set at " Ahead full speed " by a signal from the deck.

The first stop on March 9, 1898, was at San Francisco, where the *Oregon* coaled. Succeeding runs were made as follows:

San Francisco to Callao, Peru
Callao to Port Tamar, Str. of Magellan
Port Tamar to Punta Arenas
Punta Arenas to Rio de Janeiro, Brazil
Rio de Janeiro to Bahia, Brazil
Bahia to Barbados

Barbados to Jupiter Inlet, Florida—arriving there at 8:30 P. M. on 24 May, 1898, a distance of 14,511 miles having been covered at an average speed of 11.16 knots, and with an expenditure of 4202 tons of coal. A great portion of the trip was made under forced draft, and after arriving at Jupiter Inlet, she coaled, made a few machinery adjustments and on the morning of 29 May steamed off to take her place in the blockade line off Santiago, Cuba. A list of her engineer officers serving during the engagement recalls individuals who have reached high ranks and later fame in the Naval Service. They are:

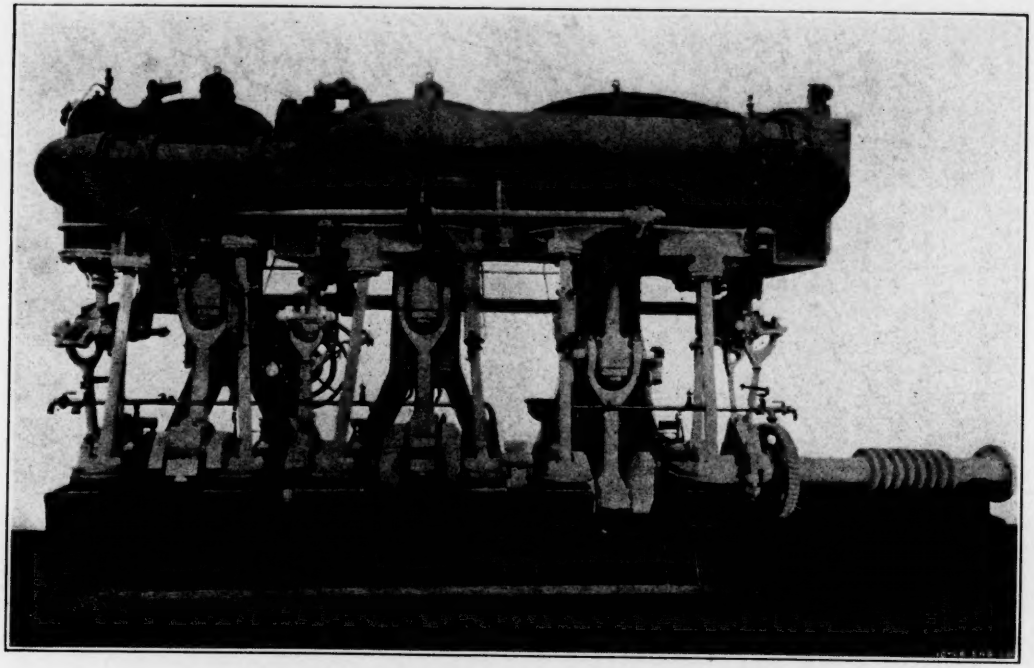
Chief Engineer R. W. Milligan
Passed Assistant Engineer C. N. Offley
Assistant Engineer J. M. Reeves
Assistant Engineer F. Lyon
Naval Cadet H. G. Jenson
Naval Cadet W. D. Leahy
Acting Assistant Engineer T. C. Dunlap.

So far little has been said of the men and ships behind the scenes. The fleet could not have existed without support from supply ships and other vessels performing a kindred duty and the lack of such vessels was amply brought out during the few months of operations. As is usual during protracted emergencies, several ships were taken over from the Revenue Cutter Service and the Merchant Marine. Two war vessels building in England for other countries were also purchased, the *Albany* (Figures 2 and 3), built by Sir W. G. Armstrong, Whitworth and Company, for Brazil, and the *New Orleans* (ex-*Amazonas*), already completed for the Brazilian Government. The *Albany* also is unusual in that her hull was sheathed with 3½-inch teak and paint filler, then covered with coal tar, tarred paper, and 24-ounce copper.

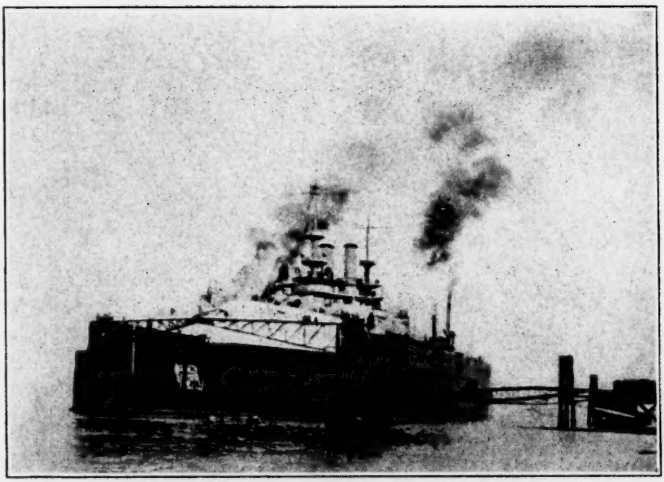
Two unusual auxiliaries, however, stand out in all this array of vessels. They are the auxiliary cruiser *St. Louis* and the repair ship *Vulcan*. The *St. Louis*, a converted merchantman, made her reputation by individual exploits, one when she took station with the patrol ships off Santiago, others being her cable-cutting ventures. Independently, she cut several cables connecting Cuba with other Spanish islands nearby, in some cases having to flee under gunfire. Most prominent of the auxiliaries was the *Vulcan*, formerly the steamship *Chatham* of the Merchants and Miners' line. She was our first repair vessel to actually serve as such and during the action off Cuba she was anchored in Guantanamo Bay, where she repaired all types of vessels.

Her services were invaluable as was shown by reports of commanding officers and engineer officers. In many instances, the engineer officer of a ship would spend entire days on the repair ship to follow up work being done for his own machinery plant. One enterprising lieutenant in command of a tug, appropriated at Key West several rapid-fire guns that had no apparent owners. The

FIGURE 3.



PORT MAIN ENGINE, U. S. S. "ALBANY," ERECTED IN SHOP.
FIGURE 3.



DOCKING THE BATTLESHIP "ILLINOIS" IN THE FLOATING DRY DOCK AT THE U. S. NAVAL STATION, NEW ORLEANS, LA., JANUARY, 1902.

FIGURE 4.

Vulcan installed them; the lieutenant demanded and received ammunition, and the tug performed in the engagements off Manzanillo. Entire boilers were retubed by the *Vulcan's* force of one hundred mechanics instead of sending the ships back to Norfolk for retubing. Torpedo boats, because of their fragile nature, constantly required repairs, and after the Battle of Santiago the battleships received her attention. She assisted further in raising and towing the sunken *Maria Theresa*. Of course, such busy hands required twenty-four hour duty and the ship's force worked three shifts per day, in two months repairing sixty-three ships and supplying sixty. Her hull being in bad condition, she was later offered for sale and in 1899 the bid and sale price of $175,500 offered and accepted marked the close of a brilliant Naval career.

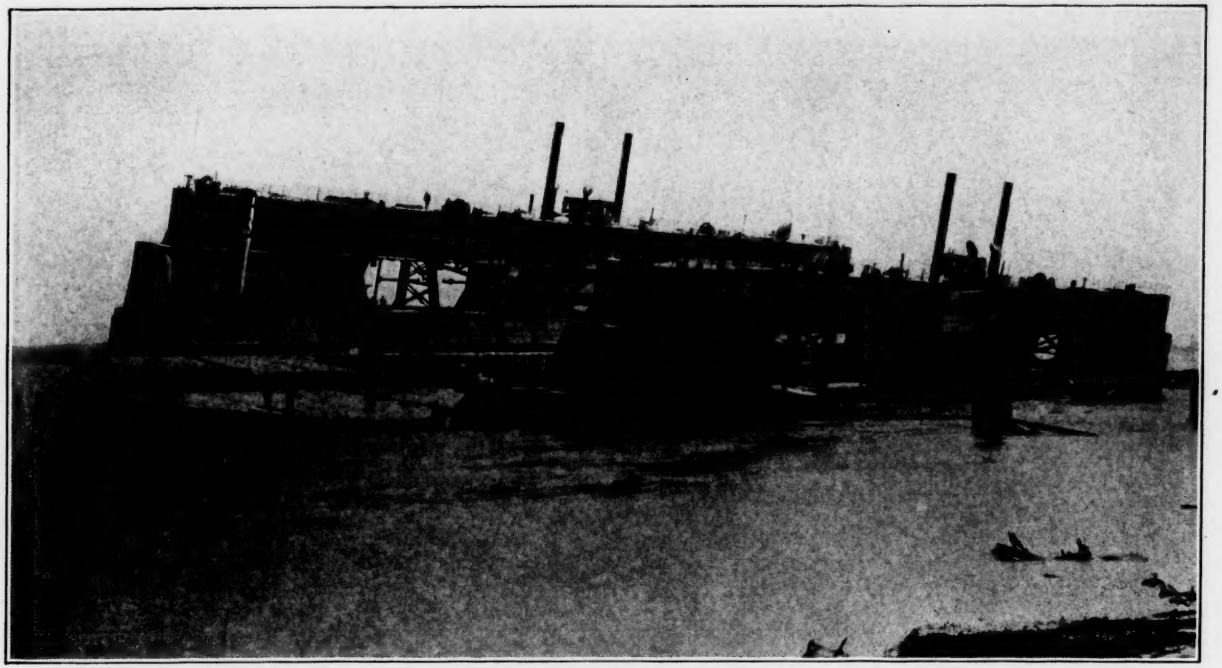
Gardiner C. Sims of the Volunteer Navy was the *Vulcan's* chief engineer and also an assistant during her fitting out. Mr. Sims became well known in later years as the president of the Harris Steam Engine Works, but is better known throughout the Navy as the inventor of the Armington and Sims high speed reciprocating engine for driving dynamos. Under his charge in the shops of the *Vulcan* were moulders', coppersmiths', blacksmiths', and boilermakers' tools and equipment such as one would expect to find in any well-ordered industrial plant ashore. The cupola in the foundry was the first " sea-going " cupola to be found in any Navy.

More can be said about the various vessels participating in the War. However, none of these could thoroughly serve their purpose and fulfill their mission without assistance from the shore and one is too prone to give full credit to the heroic deeds afloat without one iota being reserved for the " non-combatants " ashore who made the incident possible. The Bureau of Steam Engineering was a beehive of activity with Admiral Melville still holding the reins. All Navy Yards were busy, particularly in maintaining the coastal patrol established to intercept Cervera's fleet. Norfolk being the nearest Navy Yard to the scene of operations received the brunt of the load on the heavy ships. Key West was hastily fitted out as a repair and supply base and considering the haste with which the fitting out was done, a remarkable service resulted. In the Orient, Dewey's forces were still more crippled with no bases nearer than Mare Island, though after the Battle of Manila the subsequent

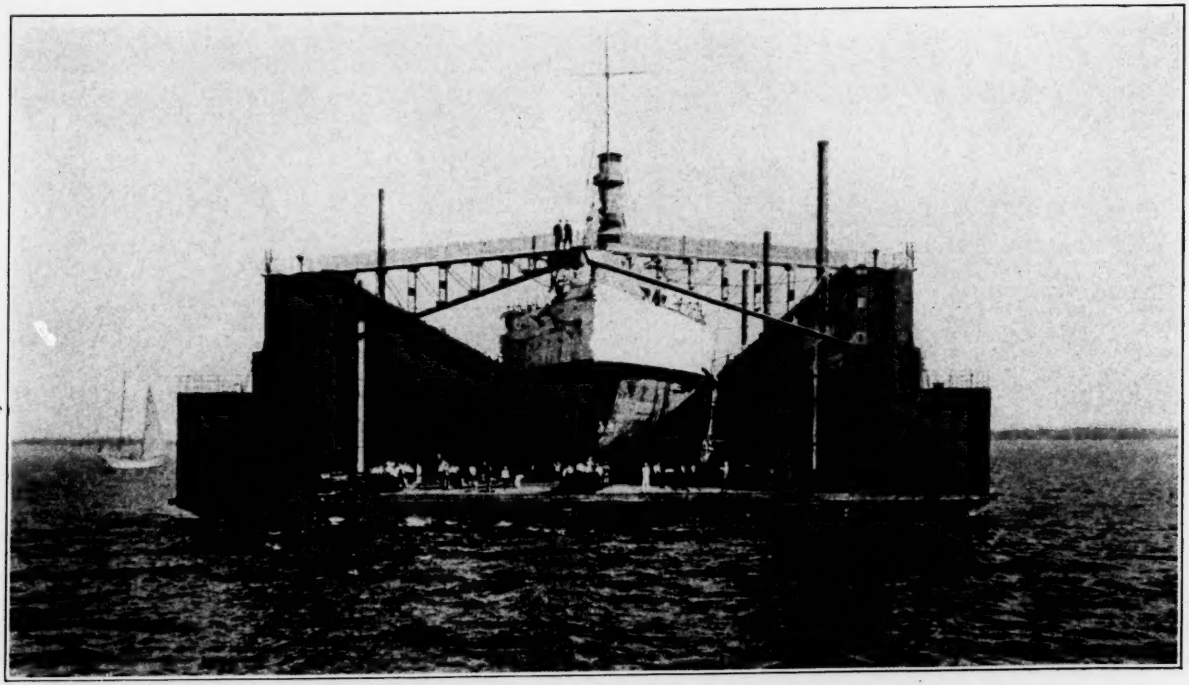
possession of the Naval Station at Cavite gave some semblance of a fourth rate repair base. A brief description will not be amiss. Most repairs there were made by natives on antiquated rattle-trap equipment whose only excuse for being called machinery was that it was the only thing available. The Machine Shop had a rough earthern floor, a leaky roof, and candle light for illumination. A large steam hammer served as a curiosity in the blacksmith shop. In the foundry, conditions were just as ancient for all charges had to be carried up the cupola by hand with no elevator available. The natives built molds of green sand and built fires under them for drying out. Split patterns were unknown, the most intricate molds being made with trowels and slickers. The prize archeologic exhibit probably rested in the pattern shop in the form of a wood-turning lathe which consisted of two parts; a table on which there were two centers, one adjustable, and a six-foot diameter wheel resembling a cart wheel. A piece of wood to be turned was placed between centers, with a rope belt around it and the big wheel, two men turned the big wheel and a third held the tool against the revolving work. The natives, however, much preferred to round off a piece of wood by sitting on a table, holding the wood with their bare toes, and working it with a jack plane.

The lack of facilities demonstrated by the war emergency, which fortunately was very short, brought out a pronounced strategical defect. As has been this country's policy in similar past situations, a rapid expansion of shore facilities took place—most of it too late to use in the war just passed. The Bureau of Yards and Docks during the first part of the next year announced plans for four large graving docks, one at Mare Island, one at League Island, one at Boston, and one at Portsmouth. Meanwhile, the largest floating drydock in the world was placed under construction at the Maryland Steel Company's plant at Sparrows' Point, Maryland, for use at Algiers, Louisiana. With its capacity of 15,000 tons, it was intended to lift the largest battleship or armored cruiser then afloat. Completed in 1901, it was towed to its destination near New Orleans that same November and placed in commission. The *Illinois* having been commissioned shortly before, the dock received its first major test by lifting the *Illinois* in one hour and fifty-seven minutes. (Figures 4 and 5.) With the success attendant on this

NEW ORLEANS STEEL FLOATING DRY DOCK.
Starboard side wall heeled out of water for self-docking and for taking bolts out of under-water connections.
FIGURE 5.



NEW ORLEANS STEEL FLOATING DRY DOCK.
Starboard side wall heeled out of water for self-docking and for taking bolts out of under-water connections.
FIGURE 5.



U. S. Floating Dry Dock "Dewey."—U. S. Battleship "Iowa"
Completely Docked.
Figure 6.

dock fresh in mind, Congress authorized a still larger one for use at Cavite in July of 1902, as the decision had been made to improve the Navy Yard facilities there. This floating dock was completed in 1905, tested by lifting the *Iowa* (Figure 6), and then prepared for its long tow across the Atlantic Ocean by way of the Azores, through the Mediterranean Sea and Suez Canal, down through the Red Sea, and over the Indian Ocean to its final anchorage at Olongapo. Towing was made difficult, not only because of bad weather encountered on the route, but because of failure to provide some type of faired bow in place of the squared ends which aggravated handling of the monster. The supply ship *Glacier,* the colliers *Brutus* and *Caesar,* and the tug *Potomac* served as escorts and towing vessels, merchant officers and crews manning the colliers and Naval officers and crews manning the *Glacier* and *Potomac.* The heavy six-inch wire lines and the fifteen-inch manila lines parted several times. Breakdowns of main engines, towing engines, a low coal supply on the tug, and the task of rescuing the dock when cast adrift made life miserable for everyone concerned. Statistics of the voyage show a best day's run of 152 miles made in the Bay of Bengal with a 40-mile-per-day current assisting, and a worst run of minus 24 miles in one day in the Atlantic while steaming against a head wind and sea. Over a half year was spent in making the trip and when the dock was finally delivered, the towing squadron left for the United States without one vestige of regret.

COMPLETELY DOCKED.
FIGURE 6.

For a good summary of the lessons of the War, particularly as regards its engineering features, there is no better exposition than that to be found in the Chief of the Bureau of Steam Engineering's Report. It is regrettable that many of these features must be emphasized by actual emergency and under fire, but the lessons are positive and we build to overcome our past defections. Admiral Melville wrote as follows:

"1. The vital necessity of giving the machinery of vessels in reserve frequent tests under working conditions, so that any defects may be discovered and remedied before war makes the vessels' services absolutely necessary. In several cases defects were found after the ships had begun cruising, and repairs laid them up in the midst of the war.

2. The great importance of having all our Naval stations in positions of strategic value properly fitted out for repairs and with adequate supplies of non-perishable stores. It had been evident for a long time that Key West was such a station, but money to put in a proper repair plant was refused year after year and only granted after the war had begun. The movement of large bodies of troops and their equipment almost blocked the railroads, so that after the beginning of the war it was almost impossible to secure the forwarding of tools and supplies.

3. That fresh water for boilers is almost as important as coal, and that a distilling ship is an important adjunct of a fleet operating away from a base where fresh water can not be readily obtained.

4. That every fleet needs a repair ship to enable the efficiency to be maintained without leaving the station, and consequently that several ships should be equipped so as to be ready to proceed with the fleet.

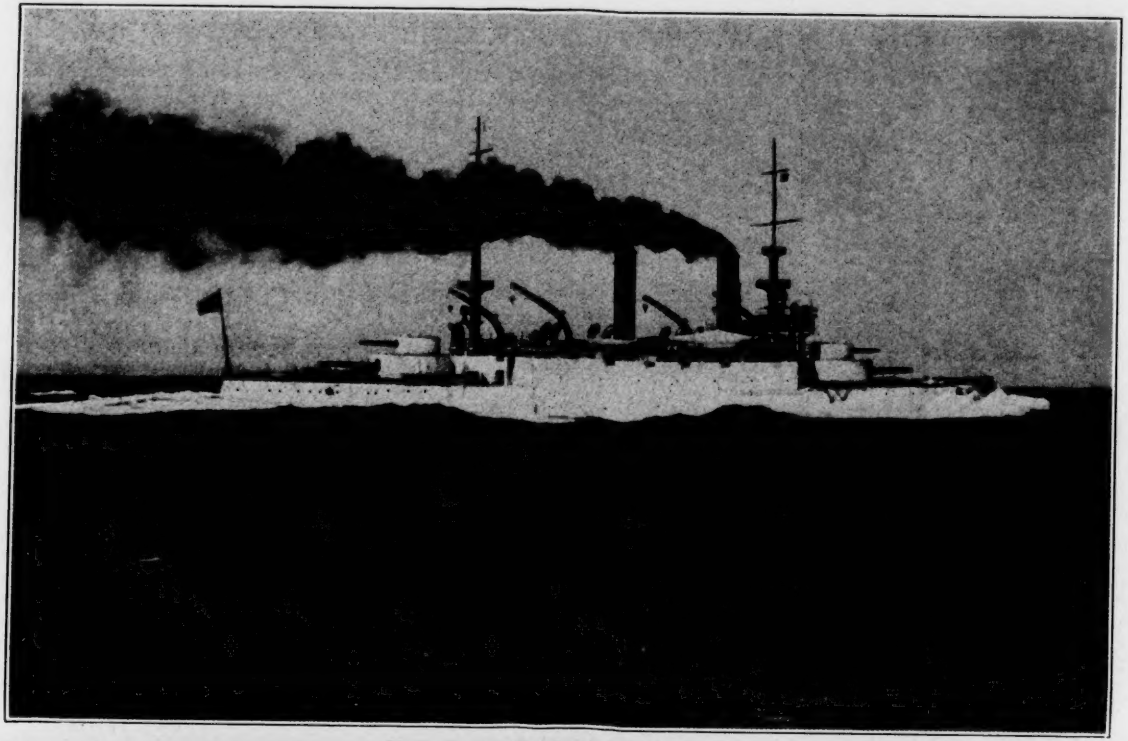
5. The great tactical advantage of water-tube boilers.

6. That if more than two main engines are to be fitted, there should be three engines driving three screws, and not two main engines on each shaft. The *New York* and *Brooklyn* had their forward engines disconnected at the time of the Santiago fight and could not stop to couple them. An accident to any part of either of the two engines on a shaft disables half the power; in the three-screw ship this fraction would be only a third.

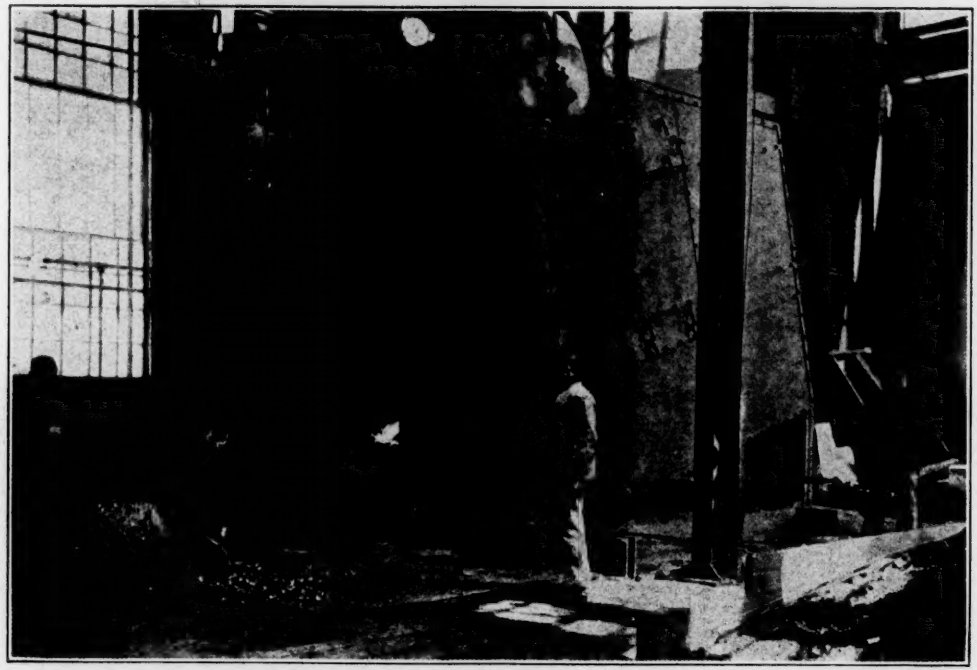
7. That there should be frequent trials under forced draft to keep the blowers in good condition and to make the men thoroughly familiar with working under maximum conditions. It appears that some of the ships had never been under forced draft since their contract trials until the day of the fight at Santiago.

8. That the location of the forced draft blowers is a matter of serious importance. In some of our ships, owing to the demand for all other space for other purposes, the blowers had to be located in corners or pockets in the fire rooms, where it was impossible for human beings to give them proper attention, owing to the intense heat due to lack of ventilation. In the *Cincinnati* temperatures as high as 205 degrees F. were noted, and the Commanding Officer when investigating the case personally, had his face scorched.

U. S. S. "KEARSARGE."—FULL SPEED.



U. S. S. "KEARSARGE."—FULL SPEED.
FIGURE 7.



ONE OF THE "ALERT'S" BOILERS UNDER TEST AT ELIZABETHPORT.
FIGURE 8.

The blowers must be placed where they can be properly cared for or else they are useless and might as well be left on shore.

9. That the *personnel* of the service should be adequate to the material. It has been notorious for some time that this is not the case, and we are providing for a decided increase in the number of vessels with no increase in *personnel*. By sending nearly every officer on the active list to sea we were able to give the regular ships a fair complement of trained ones, but had the war been of long duration we should have been greatly embarrassed to supply the places of those disabled or invalided. Volunteers, however well trained in other ways, cannot entirely replace the regular officers.

10. That we must make provision for training the enlisted men of the engineer department. Many of the colliers and auxiliary vessels had to start out with absolutely green crews, many of whom, so far from having the "sea habit" had never been on a vessel of any kind. This must be remedied if our enlarged fleet is to be efficient.

11. That our fighting ships must have the highest practicable speed. There is an almost general agreement on this point among Naval men, but if any had thought that this did not apply to battleships the fight at Santiago must have shown that the highest practicable speed is just as important in these vessels. It is very gratifying, therefore, that our three new battleships are to have speed of at least 18 knots, which is now recognized as the standard."

Bennett, in his "Steam Navy of the United States," gives an excellent history of the Naval Engineer Corps of this country up to 1897, which marks the closing period of his books. Admiral Melville, by virtue of his aggressive nature and position, was continually fighting for what he considered the rights, privileges, and educational requirements of the engineers, while at the Naval Academy two groups of students were passing through each year, one trained for the line, and one for the engineer corps. To rectify an unsatisfactory situation, Congress passed a bill approved by the President on March 3, 1899, which changed the whole *personnel* arrangement. By this act, the engineers were coalesced with the line, and assumed the ranks and title of their contemporaries in the line, the titles of "Past Assistant Engineer" and the like fading out of existence. Certain specifications of the act limited prescribed

classes of engineers to engineering duty only and provided for the transfer of other engineers below the rank of commander to general line duties upon successful completion of an examination. At the same time the cadet engineers at the Naval Academy were amalgamated with the line, all becoming midshipmen. Although the engineers had now attained the ends they sought, the amalgamation had its repercussions in later years, for so many of the younger officers were attracted to the line that few leaned toward engineering duty. Periodic complaints from the Engineers-in-Chief of the Navy failed to rectify the situation. The explosion of the *Bennington's* boiler due to a furnace collapse and the killing of 66 men served only to add fuel to Rear Admiral Raes' indignant report of 1905. In one year the older officers of the Engineer Corps who had not amalgamated had fallen from 66 to 43 with no signs of replacement. Nor was the Annual Report the only medium of complaint! Articles appeared in the JOURNAL, line officers wrote in the "Naval Institute Proceedings," letters were sent to the editor of the "Army and Navy Journal," lectures were given before the Naval War College, and yet no effective action was taken, for the Annual Report of Engineer-in-Chief J. K. Barton in 1908 warned that "engineering in the Navy must fail" due to a lack of candidates for the engineering school which had had to be discontinued because there were no applicants for the course. The entire situation may be explained by a defect in the amalgamating act which failed to provide a method for feeding the Engineers' Corps new blood.

Nevertheless, intensive and extensive development now took place in the Naval engineering field, many new types of vessels appearing on the horizon, rapidly passing by, and then vanishing. In our own Navy, dynamite cruisers were found to be *nil* in value, also such vessels as harbor defense rams. These may be classed with freak vessels of other nations of which only one or two examples appeared and remained only to be read about. Monitors, essentially large mobile gun platforms for harbor defense work, were still building, 1898 finding the *Arkansas, Connecticut* (later *Nevada*), *Florida,* and *Wyoming* authorized, the last of the monitors to be placed on the register. That same year found the *Kearsarge* (Figure 7), *Kentucky,* and *Alabama* launched, with the

Maine, Missouri, and *Ohio* authorized also. These latter were originally intended to be of the same design as the *Alabama* class with fire-tube boilers but a later change in specifications altered their engineering plant, the *Maine* receiving Niclausse boilers over the vigorous protests of Admiral Melville, while the other two received Thornycroft boilers designed with steam ends of the outer half of each tube bank discharging above the boiler water levels.

Other vessels of that year included two distilling ships, the *Iris* and *Rainbow,* intended to serve as water supply ships for the combatant vessels. They produced all water on board to the extent of some 60,000 gallons per day each, though neither was completed in time to serve with the fleet off Santiago. Motivating necessity for a distilling ship was found in the low capacity of the ship plants and the inability to secure uncontaminated water ashore, a condition frequently found dangerous. An illustration of the latter situation was found in 1899 when the *Solace* was sent to the Naval Station at San Juan, Puerto Rico, with a distilling plant on board to furnish the station with fresh water after the water ashore had been found to be very badly contaminated. Another evaporating plant, a Lillie triple multiple effect, was installed ashore at Dry Tortugas and was given a successful six-day trial.

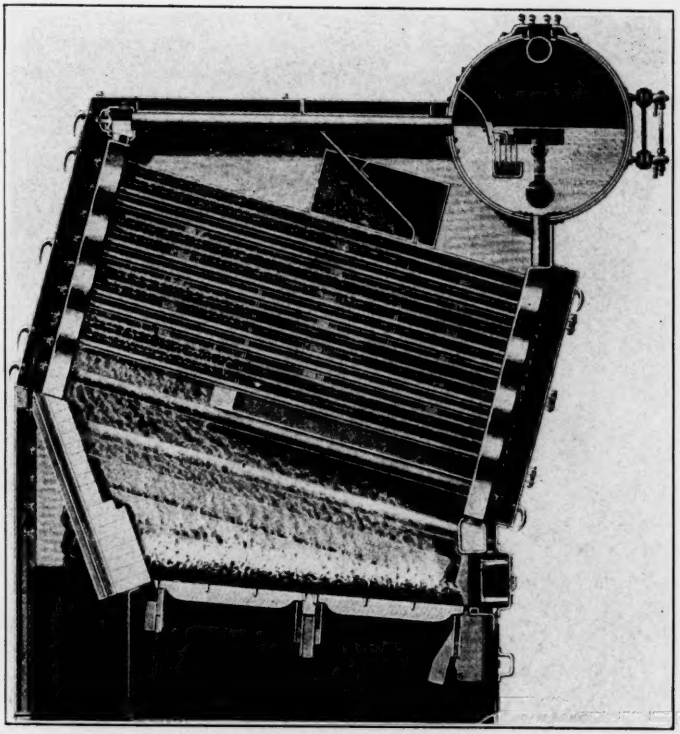
In addition to the three battleships authorized and begun, Congress provided for 16 four hundred ton torpedo boat destroyers and 12 one hundred and fifty ton torpedo boats. These were to have water-tube boilers and reciprocating engines. Just one month after authorizing this program, the Union Iron Works at San Francisco launched the *Farragut,* our first torpedo boat destroyer, an entirely new type of vessel for the United States Fleet.

To return to the *Maine.* Her boilers were found unsatisfactory from the very beginning due to poor and retarded circulation caused by insufficient area of the front headers, although tested satisfactorily at Cramp's in May and June of 1899. Because of continued breakdowns, bursting tubes, and the effect on the morale of *personnel,* her boilers, and similar ones on two cruisers and the monitor *Nevada,* were later removed and replaced with a more satisfactory type. Mosher boilers on the monitor *Florida* and Thornycroft on the monitor *Arkansas* evidently were satisfactory, for no complaint was heard from either. One very important boiler

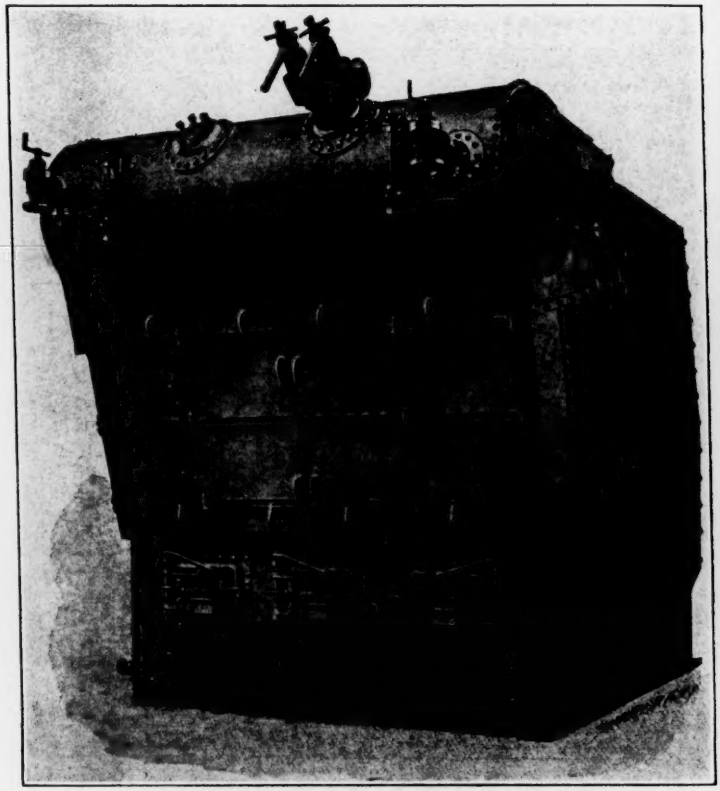
change came in with a modification to the Babcock and Wilcox boiler. The older design had its front inclined away from the vertical toward the back and the drum located at the back. In the Hoxie design, the steam drum was located at the top front angle, the tubes being inclined upward toward the back headers at an angle of 15 degrees. In short, the boiler was reversed. By making the front and back headers parallel (they still retained their sinuous shape) it was possible to use straight tubes entirely. The lower row of tubes was left at a 4-inch diameter with a baffle of fire brick laid over them for two-thirds of their length. Water walls were also provided at the sides and the entire baffling was rearranged. With this modification, the B. and W. boiler became essentially as we know it today, no further changes occurring until the advent of oil firing several years later. The new design was known as the *Alert* type, having been used to replace the worn-out boilers of the old sloop-of-war *Alert* (Figures 8 and 9). However, the cruiser *Cincinnati* (Figure 10—*Wyoming*) probably marks its first use on a new vessel, the boiler becoming more or less standard in the Navy until the demand for higher pressures and more steam at a later date caused express boilers to supplant a tried and successful type.

Trials of the *Kentucky* and *Kearsarge* late in 1899 brought in the Naval reciprocating engine much as it is known today, for these were the first large engines to be constructed entirely with turned steel columns tied together and braced by steel tie rods (Figure 11). Much comment and criticism had been directed at this design, as claims were made that the engine would not have sufficient rigidity to withstand the stresses encountered. Evidently no calamitous breakdown occurred, for we find the same type of construction used in our last reciprocating-engined ship, the *Oklahoma.*

Three more major changes occurred after the change to engine framing. As stated previously, each new authorization gradually brought with it larger ships and greater powers, and in a statement made by Admiral Melville about 1900, the large all big gun battleship was predicted though the prophecy did not reach fulfillment until 1905 when the British included their *Dreadnought* in that year's program. Of the three changes, the first was made on the armored cruiser *Washington* authorized in 1902. Piston valves



SECTION SHOWING PATH OF THE GASES.
B. & W. BOILER, U. S. S. "ALERT."
FIGURE 9.



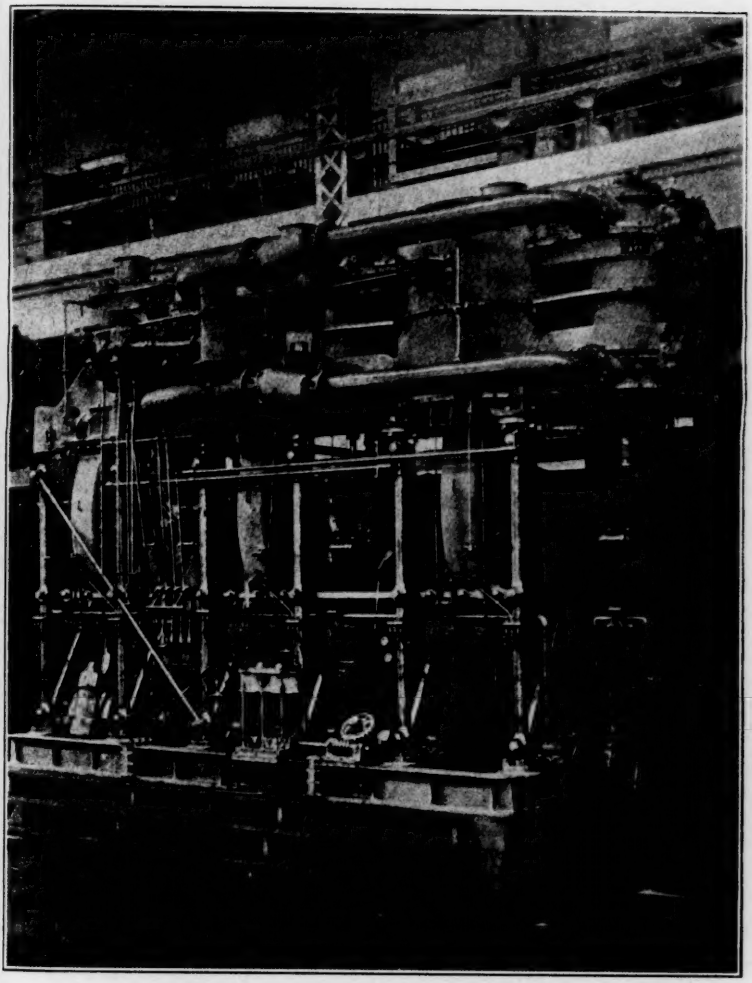
One of Four Babcock & Wilcox Boilers Built for U. S. S. "Wyoming."*
Patented.
Figure 10.

were in general use, but as engine weights increased component parts increased in size, which in turn set up heavy inertia stresses in moving members. Early numbers of the JOURNAL are replete with discussion and calculations of such stresses. Lovekin now came to the fore with a design of an assistant cylinder for each valve, a small cylinder being located on the valve bonnet and by means of a piston attached to an extension of the valve rod the weight of these moving members was relieved from the eccentric. A similar installation followed on the battleship *Kansas* (Figure 12). When the *Michigan* and *South Carolina* were authorized in 1905 a distinct and very advantageous improvement was made in the design of their engines. Older reciprocating engines had been designed with a considerable difference in power delivered by each cylinder with consequent vibration and torque variation attendant. In this new arrangement, each cylinder was designed to furnish the same horsepower as its neighbors. Piston speed was stepped up to 1000 feet per minute and 50 degrees of superheat was added to the new 265-pound pressure. Further improvement was made by increasing the length of the valves, enlarging the steam ports, and shortening the steam path. Reduced steam velocities resulted, and also less pressure drop between the valve and cylinder. Third and last of the improvements came with forced lubrication which apparently had paradoxically been inherited from the turbine. Credit for its first use belongs to the British who installed a forced lubrication system in 1901 on a torpedo boat destroyer, the *Syren*. In the engines of this vessel the oil was forced through a hollow crankshaft and thence to all bearings, the overflow returning to a reservoir for reuse. Next on record was the application of forced lubrication experimentally to one main bearing and a crank head of the cruiser H.M.S. *Carnarvon*, with such success that a system was installed in the battleship *Brittania* in 1905. H.M.S. *Africa* had a similar installation. In the United States Navy, lubrication was by means of gravity feed, a system of small tanks or reservoirs located at various parts of the engine feeding into tubes leading to the parts to be lubricated (Figure 13), as shown by the installation on the cruiser *West Virginia*. A year later, 1906, marked the addition of forced lubrication to our largest vessel, the *Delaware*, which was laid down the following year. The system was rapidly added to

other vessels then in commission because of its decided advantages. At first the *Delaware* was to be forced lubricated only to her main and crank-pin bearings and to the eccentrics, with gravity feed for all other external moving parts. On her trials, those parts with gravity feed ran warm and by a makeshift arrangement through temporary connections and alterations of the water service piping, forced lubrication of all parts was a demonstrated success for its superior efficiency and economy in oil expenditure. That a considerable saving resulted is shown by a comparison with the older gravity lubricated engine in which one gallon of oil per day was entirely consumed for each 100 I.H.P. The recovery resulting from forced lubrication in a unit of 20,000 or more horsepower was therefore considerable. Incidentally the period from 1905 to 1907 marks the beginning of the development of strictly mineral oils for general lubrication although mineral oil had been used exclusively for cylinder oil in accordance with a General Order issued in 1879.

Frequently a change is parent to a change in some other related part. Forced lubrication was in this category when oil on the piston rods was drawn into the low and intermediate pressure cylinders by the differential of pressure at the packing box. Since the carry-over of oil into boilers with the feed water caused serious trouble, piston rod steam seals now became necessary on the L.P. and I.P. stuffing boxes.

Boilers have been mentioned previously, but a few of the minor changes should be briefly mentioned at this point. In 1898 solid or seamless drawn steel boiler tubes were first brought to the attention of Naval engineers. Their advantage was marked and they were adopted almost immediately, but peculiarly enough a condition of corrosion and pitting arose that required considerable study before it was overcome. On the torpedo boat *Davis,* a serious accident took place late that year when several boiler tubes pulled out of a drum, killing seven men and scalding others in so doing. But the demand for better and bigger boilers continued, nickel-steel rivets coming into use for boiler drums. Charles Ward in 1899 discussed the need for steam pressures of 250 to 300 pounds. The British were placing Belleville boilers in their battleships, the *Goliath* being one of them. In Japan, Captain Miyabara brought



One Main Engine, U. S. S. "Kentucky."
(Set Up in Shop.)
Figure 11.

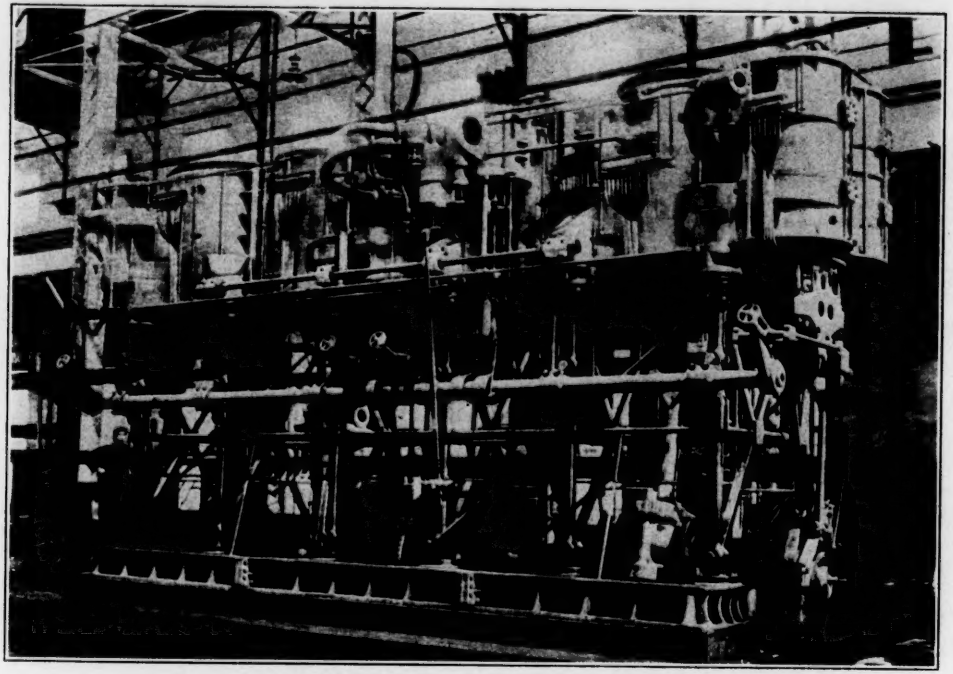
the JOURNAL a translation of a German article dealing with the difficulty of protecting superheater tubes. Although previous mention has been made of the *Arkansas* boilers as being satisfactory, considerable corrosion trouble was encountered in the upper tube areas. In this type of boiler the upper tube ends were not of the "drowned type," but when the drum water level was raised experimentally, all corrosion troubles disappeared.

Change being the order of the day, it is remarkable that so few new types appeared, freak ships being practically absent from the roster during the period now being discussed. The changes which did occur were principally on the side of quality and quantity on then existing types. It is true that electrical propulsion by storage batteries for United States torpedo boats was discussed in 1898 and 1899 but nothing came of the discussion. The British, following Sir Charles Parsons' *Turbinia,* were not slow in making use of turbines, turning out the *Cobra* and *Viper,* torpedo boats. As in the *Turbinia* they were multiple propellered, having four shafts and eight propellers. How successful they were or would have been is unknown, for, regretfully, structural weakness of their hulls developed, and both ships foundered. Special astern turbines were provided in these ships and on trials in May, 1900, the *Viper* attained a mean speed ahead of 34.75 knots on her two best runs.

Protection of battleships was given much consideration and in all our battleships from the *Kearsarge* to those authorized in 1903, corn pith cellulose was placed in the hulls as a protective belt. A factory for furnishing this material was built in the middle west. One could say that authorization of the *Georgia, New Jersey,* and *Pennsylvania* in 1899 almost brought the Navy Department and the steel manufacturers to blows. Three ships of 14,000 tons and 19 knots speed were held up for sometime until the steel manufacturers came down with their armor prices to a demanded level of $300 or less per ton. This price was met and the ships were built. Several battleships were built with sheathed hulls, two being awarded to the Newport News Shipbuilding and Drydock Company in 1901. The U.S.S. *Chesapeake,* launched in June, 1899, was one of the first sheathed war vessels to be built in this country.

Among other hull structures that were novel in appearance, the *Illinois* class of battleships may be cited, with its two smoke-pipes

ONE MAIN ENGINE, U. S. S. WEST VIRGINIA.
FIGURE 13.



One Main Engine, U. S. S. "West Virginia."
Figure 13.

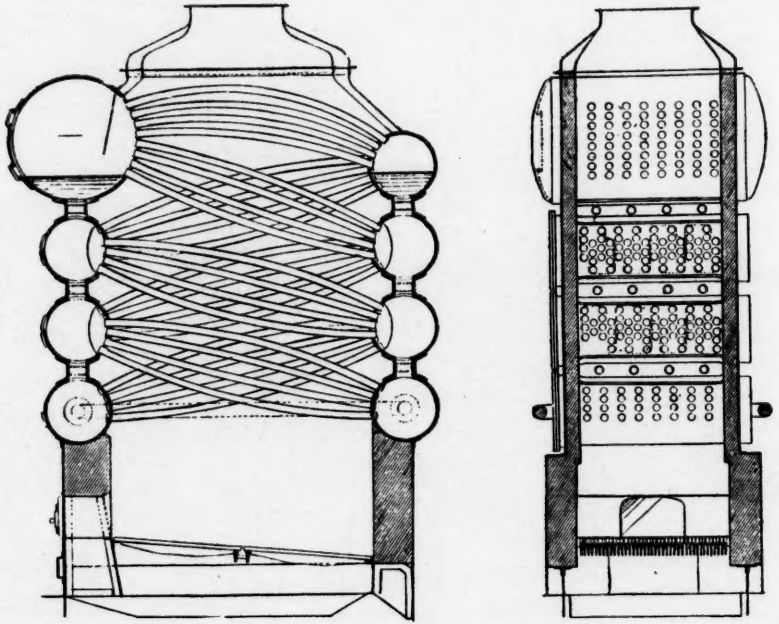


FIGURE 14.—THE MIYABARA WATER-TUBE BOILER.

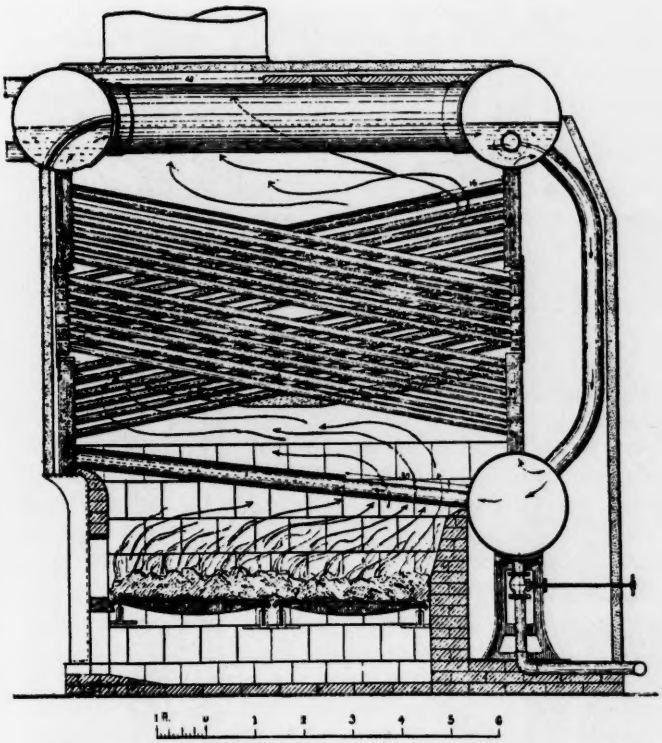
abreast (Figure 17). Rotation of screws also came in for a considerable share of comment, a few ships, including the destroyer *Decatur* (Figures 18, 19 and 20), being fitted with in-turning screws where before the majority had out-turning propellers. Efficiencies of propulsion as affected by the direction of rotation of screws was under general discussion, advocates of in-turning and of out-turning screws being found in every country. When the *New Jersey* class of battleships was authorized, the triple screw idea of Melville was discarded because of tactical considerations, no such designs having appeared in this country since except for our turbo-drive destroyers. A further new feature appeared in the 1902 bill when Congress provided for construction of new vessels in Navy Yards, all construction prior to this having been done by private shipbuilders. Under the new arrangement, the *Connecticut* was scheduled for construction by the Navy Yard, New York. She also marked the advent of our first class sea-going battleships, which then displaced 16,000 tons. Our last two coast battleships, the *Mississippi* and *Idaho*, of 13,000 tons, were authorized at the same time. It is at this point that the line of demarcation really occurs between the Navy of 1883 and the Navy of today for with the *Connecticut* cruising radius and sea-keeping qualities had become the vital considerations.

After the British trials of the turbine on the *Viper* (first turbine drive vessel of war in any nation), *Cobra*, *Velox*, and cruiser *Amethyst*, a German magazine, "Uberall," predicted early in 1905 a change in English battleship types. The prediction came to fulfillment later that year when an 18,000 ton battleship with ten twelve-inch guns, turbine propulsion, Babcock and Wilcox boilers, and powered for 21 knots, was included in the annual estimates. Selection of the name *Dreadnought* for this ship has become a synonym for all succeeding large fighting ships and marks the passing of a dual battery on battleships, those which followed in practically all nations standardizing on a single major caliber gun for the main battery.

However, since turbines are the subject of these paragraphs, some other turbine ships should be mentioned here. A 1903 issue of the JOURNAL cited the German cruiser *Merkur* to be the first of that country to be fitted with turbines, six being installed. No

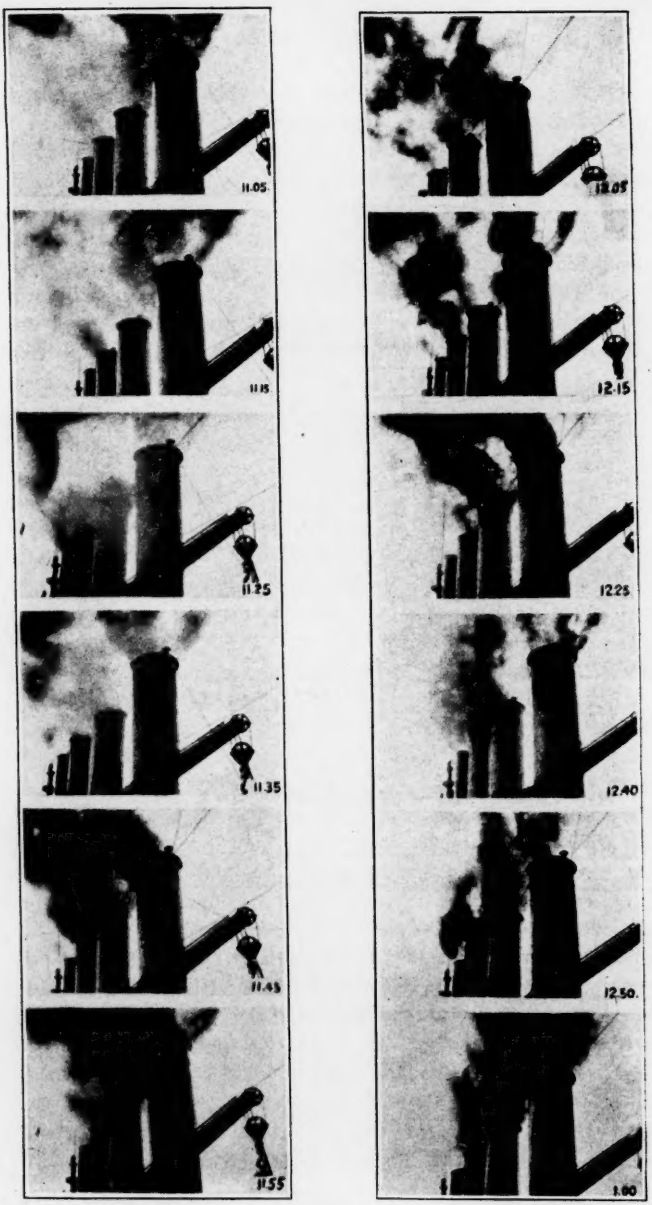
further note appeared in later issues, but in 1905 a note was made that the cruiser *Lübeck* was equipped with Parsons' turbines and later the *S-125* destroyer with turbine propulsion. Meanwhile France was not idle, for the Rateau turbine found use as motive power on two destroyers. Not until 1908, though, do we find any Japanese ship with turbines, the *Ibuki,* built at Fore River, Massachusetts. In the merchant marine, the year 1901 marked the first commercial application of turbine propulsion when the *King Edward* was begun. In the United States the *Governor Cobb,* a coastal vessel completed in 1906, was the first American commercial application. She was fitted with Parsons turbines and a hull built by Roach. In that same year Cunard of Britain projected the turbine ships *Lusitania* and *Mauretania,* which for many years held the Atlantic blue ribbon. It is recorded that the *Russia* of that line was the first turbine steamer to enter New York harbor. England also built the first Japanese turbine steamer, *Hirafa Maru,* in the year 1908. Turbine ships were building in great numbers and the reciprocating engine, which had held the field for over one hundred years, was now passing into its twilight. The *Kronprinzessin Cecilie,* built during this period, was probably one of the last and largest of all reciprocating steamships. Her shafts were 25¼ inches in diameter and powered by 24,000 horsepower.

If the preceding paragraphs have been monotonous they have been deliberately so to prepare the reader for the situation in the United States Navy. Parsons until 1902 had had a monopoly on the international turbine situation, but in that year appeared a newcomer, the Curtis turbine, a velocity compounded impulse turbine installed on the yacht *Revolution,* tests of which were observed by a board of Naval officers a year later. Charles Curtis had invented his turbine in 1895 though shortly after that date he transferred his rights to the General Electric Company, which exploited and further developed his invention. Finally, after many reports favorable to turbine propulsion had filtered in from Europe, the Navy Department decided to try out by experiment the comparative merits of the new and the old. It may be added here that the principal objection to the turbine was its inability to reverse. In an effort to settle the merits, Congress authorized three scout cruisers, the *Birmingham, Salem* and *Chester* in 1905. Originally



THE HOHENSTEIN EXPERIMENTAL BOILER USED IN THE NAVAL TESTS, ARRANGED FOR COAL BURNING.

FIGURE 15.



U. S. S. "PENNSYLVANIA."
Photographs of smoke taken at ten-minute intervals during trial.
Run south (Cape Porpoise towards Cape Ann).
FIGURE 16.

their plans called for reciprocating engines and 24 knots speed. Six firms bid, the Maryland Steel Company offering turbines as an alternative, the New York Shipbuilding Company offering Westinghouse turbines with either two or three shafts, Cramp offering Parsons turbines on three or four shafts and cruising turbines in addition, and finally the Fore River Shipbuilding Company offering Curtis turbines. Contracts were placed as follows: the *Chester* to the Bath Iron Works with Parsons turbines, the *Birmingham* with reciprocating engines (a Department design) went to the Fore River Shipbuilding Company, and the *Salem* with Curtis turbines to the Fore River Company also.

The *Chester* (Figures 21 and 22) had four shafts, and on her trials made 26.22 knots, the highest cruiser speed ever made up to that time. When she returned triumphantly to port, a blue ribbon was flying from her masthead, the speed painted on her stacks, and brooms were lashed to her masthead and yardarms in commemoration of her record. Her outboard shafts turned inboard, and the inboard shafts turned oppositely. The *Salem* (Figure 23), like the *Chester,* had forced lubrication for her turbines though her general machinery arrangement was somewhat different due to her use of Curtis turbines built exactly the same but reversed end for end when placed in the hull so as to give opposite directions of rotation on the shafting. The reader will observe that on one shaft (the port in this case) the turbine steam thrust partially balanced the propeller thrust, while on the other the steam and propeller thrust were additive. Further complications were encountered when the nozzles and blades eroded in service, changing their form and consequently their economy. Further irritation with the *Salem's* turbines was caused by their method of assembly. Interstage diaphragms were made in one piece, and to renew the shaft packing of any one diaphragm meant stripping the shaft up to the required point. The *Salem* design was somewhat unusual particularly after the Fore River Shipbuilding Company had designed the S.S. *Creole* with each turbine to the opposite hand.

Reviewing the performance of the reciprocating steam engine as against the steam turbine, the reciprocating engine was found the winner in almost all phases. Admiral Dyson states that for speeds up to 20 knots, the reciprocating engine was superior to the Par-

sons turbine, and up to 21 knots it excelled the Curtis. The turbines had a much greater overload capacity than the engine and also greater reliability, though after actual service over a considerable period the reciprocating engine proved superior. Because of its longer period of development, the Parsons turbine proved slightly better than the Curtis.

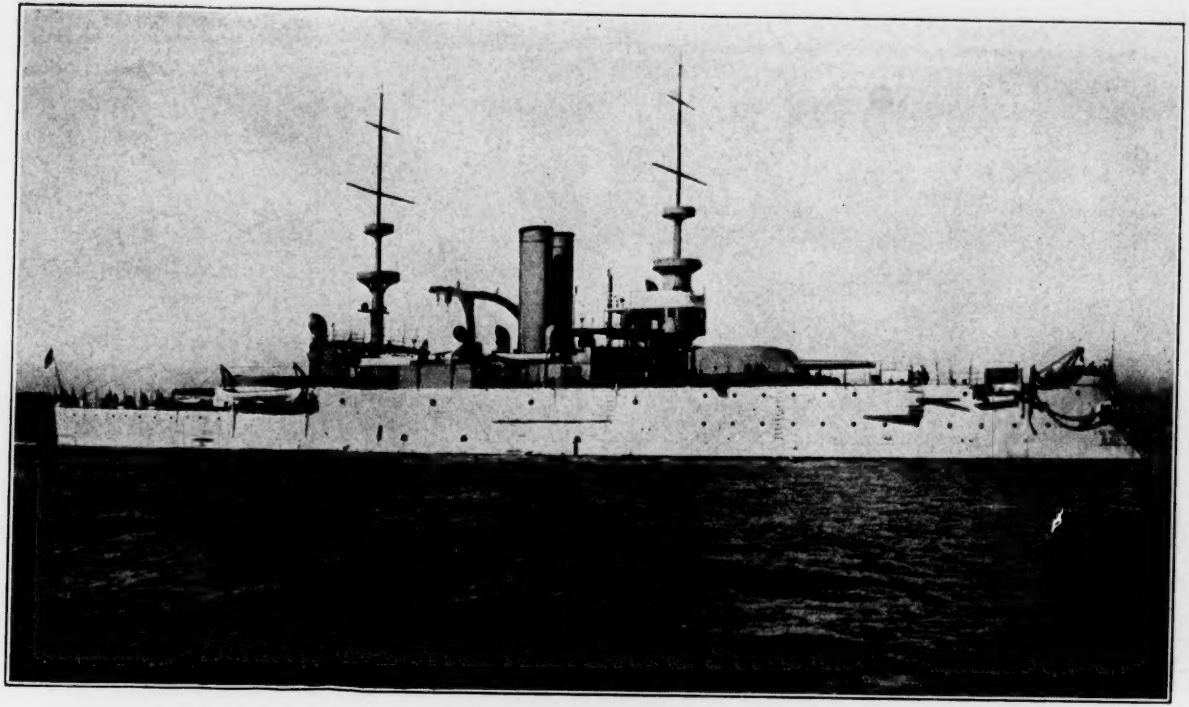
After these three vessels had been begun, a decision was made to try a comparison on a larger scale. Two battleships were authorized in 1906, one the *Delaware* with reciprocating engines, and the other with Parsons turbines, the *North Dakota.* After results from the performances of these two battleships were tabulated and compared, the reciprocating engine again won out, a damper thus being placed on the further use of turbines. Other developments were to take place on later ships but they occur at a date later than this period and will be reserved for discussion in the next article.

Some improvements had been made to the *North Dakota* turbines despite their similarity to the *Salem's,* chiefly the addition of two additional stages of blading, and the introduction of drums in the Curtis turbine, a single drum carrying the last four stages. Although our first Curtis turbines were partial failures, they had one very beneficial result—the United States Navy now procured its turbine plans in this country instead of having to go abroad.

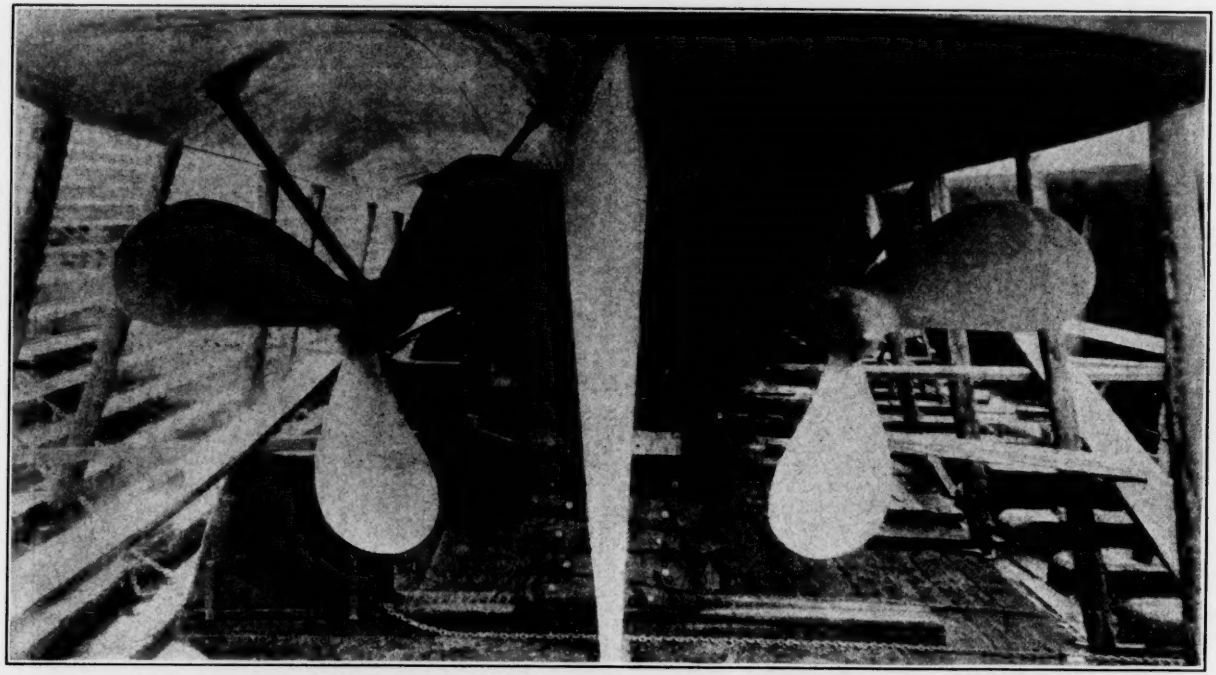
1906 marked another milestone with its authorization of several destroyers. The past torpedo boat designs because of their hull lines, had caused several vessels to fail on their contract speed requirements. An arched tunnel over the screws had reduced their efficiency and in view of the contract terms many of the builders were forced to accept adverse settlements, two companies failing as a result. The later destroyers were accepted unqualifiedly with turbines as their prime movers, the first vessels being three-shaft arrangements with Parsons turbines. Following these came a few with Curtis and Zoelly turbines (*Mayrant* and *Warrington*) with two shafts, a design which was adopted for all future destroyers because of its maneuvering qualities. The Fore River Company even went so far as to build a 250-horsepower turbine for a 50-foot Navy cutter.

Our ten-year period marks along with its many turbine ships and its final development of the reciprocating engines the genesis of

U. S. S. "Wisconsin."
Figure 17.



U. S. S. "WISCONSIN."
FIGURE 17.



PROPELLERS OF U. S. TORPEDO-BOAT DESTROYER "DECATUR."
FIGURE 18.

many new auxiliaries which added to the efficient and reliable performance of marine machinery plants. Only a brief summary is necessary though important. Automatic stokers had been tried in 1898 for the merchant marine though never adopted by the Navy. Electricity had been coming into use very rapidly, and of course, it had its staunch advocates who agitated strongly for its adoption as an auxiliary drive, pointing out that it was being tried experimentally abroad in 1899. Even standardization of machinery units was proposed. These were but a few of the suggestions then being made, though the more stable of those in authority favored a gradual extension and adoption of those things new.

The *Kentucky* and *Kearsarge* received as part of their auxiliary equipment multiple effect evaporators, all ships previously having been equipped with single effect. However, even though efficient and economical, they were condemned for several years due to a lack of capacity caused by compounding. Contentment of ships' crews had a considerable weight in this decision. With the Parsons' turbines on the *Chester* came Parsons' augmenters and dry air pumps. Weir dual wet and dry pumps followed, also rotary air pumps which lasted but a short while when it was noted that they carried away a considerable amount of fresh water condensate with the sea water seal. Even condensers were not exempt from change, examples of new types being the Morrison "Contraflow," Weir "Uniflow," and the Lovekin condenser. All tended to bring engineering to a higher state of operating efficiency by reducing the back pressure in the system or conversely increasing the vacuum, particularly in turbine plants.

Refrigerating plants had become progressively larger though the Allen dense air machine remained standard for many years. Examination of captured Spanish vessels disclosed carbon dioxide compressors which our Navy was slow to adopt. One-ton machines had given way to two-ton machines on the *Illinois,* followed by three-ton on the *Pennsylvania.* No further change, however, occurred to the ice machines during these ten years except their use for magazine refrigeration on some vessels.

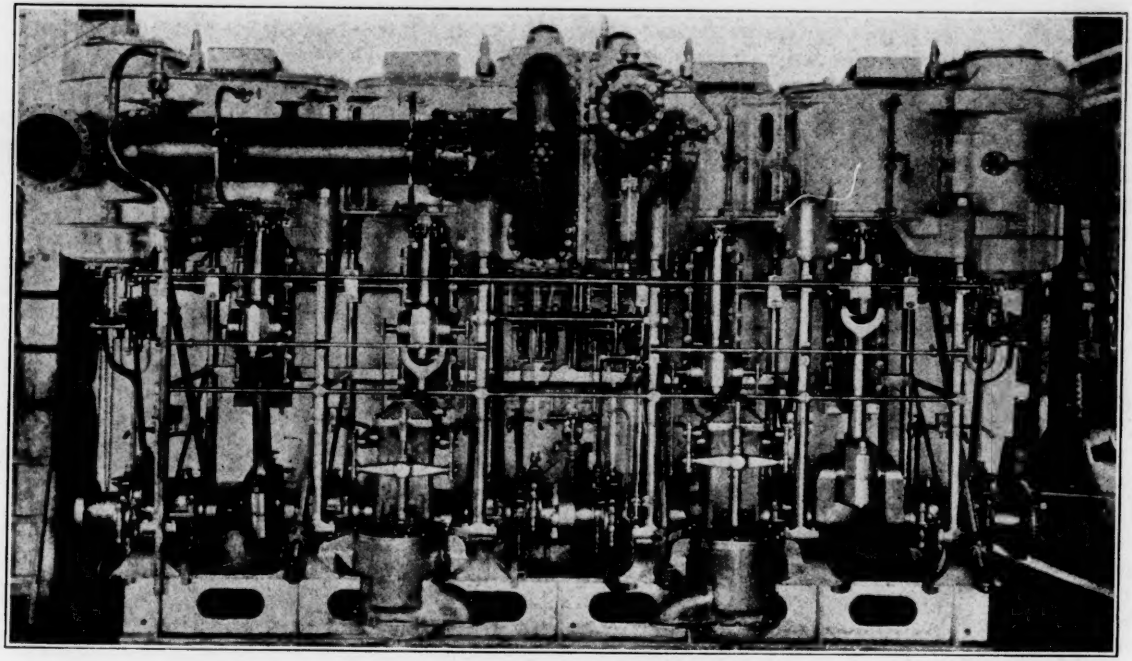
Of other important additions there may be mentioned several which were signs of the passing of the old. Reciprocating engine blowers disappeared and in their place came the Sirocco electric

drive blower on the *Michigan,* which installation resulted in a smaller and lighter unit though of higher speed. It may be added that the *Michigan* also served as an experimental installation, for steam pipe bends were used as expansion joints instead of the old slip type. Success here was negligible and the idea was abandoned for several years though steel feed water pipe was continued. A year thereafter another change to the blowers took place, this time in two of the 1906 destroyers where turbine driven blowers were specified. The Terry Turbine Company met the requirements of a good blower turbine even if a mistake in design was made in so mounting two blowers in one engine room that a reverse air flow due to the differential in air delivery by each blower caused one to be wrecked. Despite objections of some ship contractors to the use of turbine driven blowers on the grounds of poor economy they had come to stay because of their reliability.

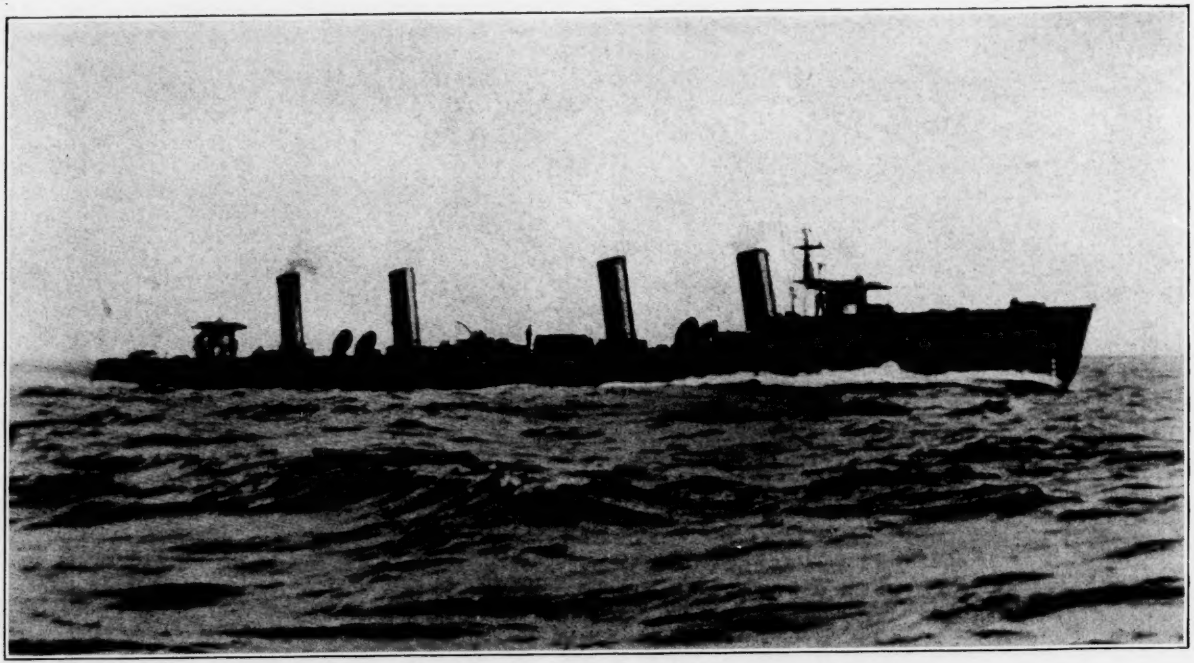
The DeLaval Company in 1904 had made a series of tests on turbine driven pumps and blowers none of which had appeared in the Navy. A year later turbine driven pumps made their debut when the *Salem* was projected with a turbine driven centrifugal hotwell pump. Further auxiliary equipment also helped to lighten back-breaking labor. Destroyers always having been fruitful fields for practical experimentation, the *Lawrence* and *MacDonough* were fitted with ash ejectors following the turn of the century. Their lead was soon followed by other torpedo boats and destroyers, then by the installation of ejectors in the *Birmingham* and *Chester,* with the result that they became standard equipment on all Naval coal-burning vessels.

Two additional mechanical features of interest may be cited before passing on to the remainder of our historical sketch. In the old reciprocating engines power was measured by means of steam indicator diagrams taken on each cylinder. A steam turbine did not permit use of such a simple instrument and some other means had to be invented to register the power developed in each shaft. Torsion meters were then developed which gave the actual shaft horspower developed by measuring shaft twist, the first meters appearing on the cruisers in 1907. The other feature concerned turbine gland seals to prevent the entrance of atmospheric pressure. British and American practice differed here, the British using steam

ONE ENGINE OF U. S. DESTROYER "DECATUR."
FIGURE 19.



ONE ENGINE OF U. S. DESTROYER "DECATUR."
FIGURE 19.



THE U. S. DESTROYER "DECATUR" AT TWENTY-EIGHT KNOTS SPEED.
FIGURE 20.

seals and the American using water seals. Water seals were short-lived, steam seals taking their place and continuing in use to the present, not, however, without change.

After the *Kearsarge* and *Kentucky* had been equipped with 160-volt electrical circuits not much change took place in distribution until the armored cruiser *Colorado* appeared on the scene with its 125-volt installation in 1900. Principal reason for the change could be found in the difference between shore and Naval practice, shore practice using 110 to 120 volts and all shore equipment being standardized to that voltage including electric lamps. This left the Naval installations non-standard and all items applying to it were then of a non-commercial nature. The *Maryland, West Virginia,* and *Pennsylvania* which were authorized shortly thereafter acquired the reputation of having the largest generating plants of any vessels in the United States Navy with three 100 Kw. and four 50 Kw. generators. That reputation was short-lived, for the following years brought the *Louisiana* with eight 100 Kw. generators and Ward Leonard turret control. Additional electrical features such as the "Long Arm" System of operating watertight doors with electric motors appeared on the *Vermont,* also a Cory three-wire telephone to replace the six-wire system of the older Bell installation. Even early experiments on underwater sound transmission were carried out.

All of these early electrical generators were powered by reciprocating engines though the later ones used a cross-compound engine of General Electric manufacture which was considerably more efficient. When the *New Hampshire* appeared on the scene all of this was changed, for now two horizontal General Electric-Curtis turbines each driving a 200 Kw. 125-volt direct current generators replaced the old. A 300 Kw. unit appeared in the succeeding program and electrical generation aboard ship had entered its second last phase as a secondary power distribution system. Rumblings of greater uses for electricity were heard dimly but nevertheless ominous. Contemporaneously electric heating and cooking devices were being investigated and searchlights with gold-plated mirrors were tested. Unassumingly, electric propulsion on a large scale was being recommended, the "Scientific American" in 1907 carrying an article proposing electric drive for ships, princi-

pally for intermediate speed reduction between turbines and propellers.

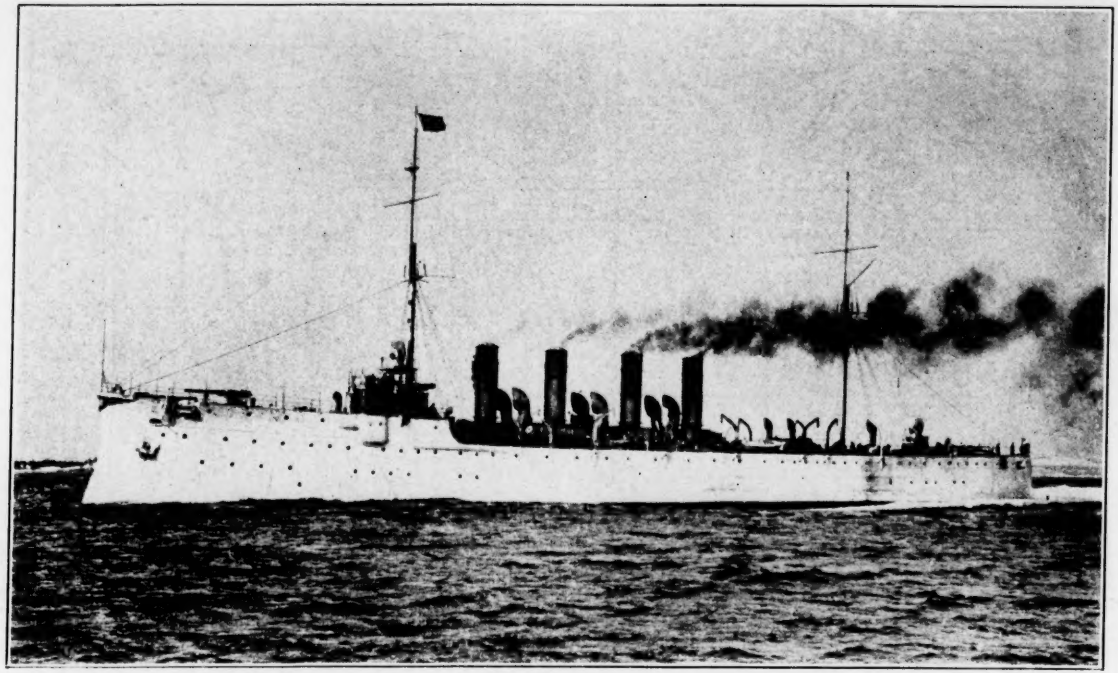
Where the reciprocating engine had filled the general period from 1814 to 1905 in Naval propulsion, its century of superiority was fading out with the turbine's rise. Another fight for supremacy was taking place with oil competing with coal for fuel honors. Experiments had been conducted on the *Stiletto* by converting her to an oil burner in 1897. The experiments were a failure and the *Stiletto* was converted back to a coal burner and returned to the Bureau of Ordnance. The English, too, shared our regret when in 1899 they expressed keen disappointment over the failure of their fuel oil burning experiments on the *Surly*.

The question of oil fuel was interesting for logistic reasons. In the first place oil was desirable because of its small bunker capacity as compared with coal and it offered obvious advantages far superior to coal. Yet it had certain definite disadvantages, among these being its inflammability, and at that time, its high cost, a doubt as to availability in quantity and source, and the expense of establishing new supply bases in addition to coaling stations then existent.

Further tests on oil burning were carried out in 1899 in accordance with a previous plan of the Bureau of Steam Engineering. In these early tests all atomization of oil was either by means of compressed air or steam, the consequence being that only three-fourths of full power was developed in the torpedo boat *Talbot* under test. There appears to have been no definite plan to these tests except to carry out the provisions of the 1899 Act of Congress authorizing them. Further difficulty was encountered at speeds above ten knots with heavy smoke discharges, the same as when burning soft coal. The experiments were transferred to the Navy Yard, New York, in 1900, to eliminate the waste effort encountered on the shipboard installations. All this was due for a change, however, when in 1901 the Spindletop Field in Texas was discovered, answering definitely the question of supply.

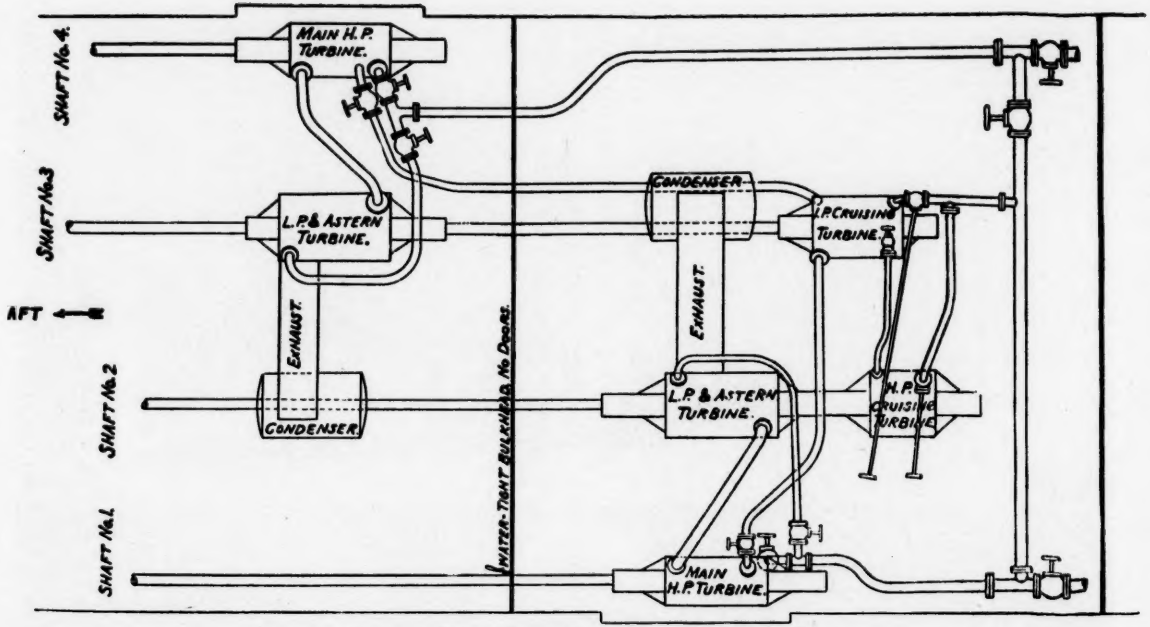
Although other nations were experimenting sporadically with fuel oil, trying various combinations aboard ship, coal and oil, and oil only, or coal on one set of boilers, and oil on another group, such as the British plan on the six after boilers of the cruiser

U. S. S. "CHESTER."
FIGURE 21.



U. S. S. "CHESTER."

FIGURE 21.



PARSONS STEAM TURBINE ON U. S. S. "CHESTER."
FIGURE 22.

Arrogant, it remained for the United States to step in and determine positively what benefits would accrue. This solution was furnished fortunately through a "double-barrelled" situation that arose. The water tube boiler situation was still unsettled and when a contractor offered his boiler for test as being suitable for Naval use, and also relieved the Government of financial responsibility for that test, the Navy Department accepted willingly. Twenty thousand dollars had also been made available for fuel oil tests just before. The Bureau of Steam Engineering then combined the two tests into one beginning in 1902 in Washington. Two and a half years were occupied in making the various experiments that made up the entire test, the results finally being published in 1904, a reproduction being printed in Volume 16 of the JOURNAL. Aside from the technical features of the reports its form and makeup set a model for all future reports of a similar nature, both American and foreign. The boiler part of the experiment proved the deficiency of a circulating tube boiler insofar as Naval use was concerned. The burning of fuel oil gave a different story, for from that time on the desirability of its future use was unquestioned. A regrettable feature of the entire series of experiments was the almost complete use of steam for atomization to the practical exclusion of mechanical atomization, though a few runs of the latter were made. This is surprising in the face of the Patent Office's experience at that time when it was given as much work filing fuel oil burner applications as for the car coupler inventions which were flooding the office.

Certain paragraphs of the report illustrate the strategical importance of oil as a fuel.

"5. That the evaporative efficiency of crude and refined oil is practically the same, no matter from what locality the oil may come. The danger of using crude oil, however, is much greater. As it should not be an expensive matter to build refineries near one of the terminal points of a pipe line, the expense of such refining should not increase to a perceptible degree the cost of such fuel, since the sale of the by-products of crude oil would often pay in great part the expense of distillation." In December, 1902, the *S.S. Progresso* was destroyed by an explosion of crude oil. Some years later the first large pipe lines came in and today the

country is crossed with several lines. One by-product, gasoline, has now become the principal product with the ascendency of the automobile.

"13. That no design of oil fuel installation should be permitted for marine purposes which would not permit renewal within twenty-four hours of all grate and bearing bars, so that a return to coal could be accomplished within a reasonable time in case of failure of oil supply." Today it is questionable whether that would be possible.

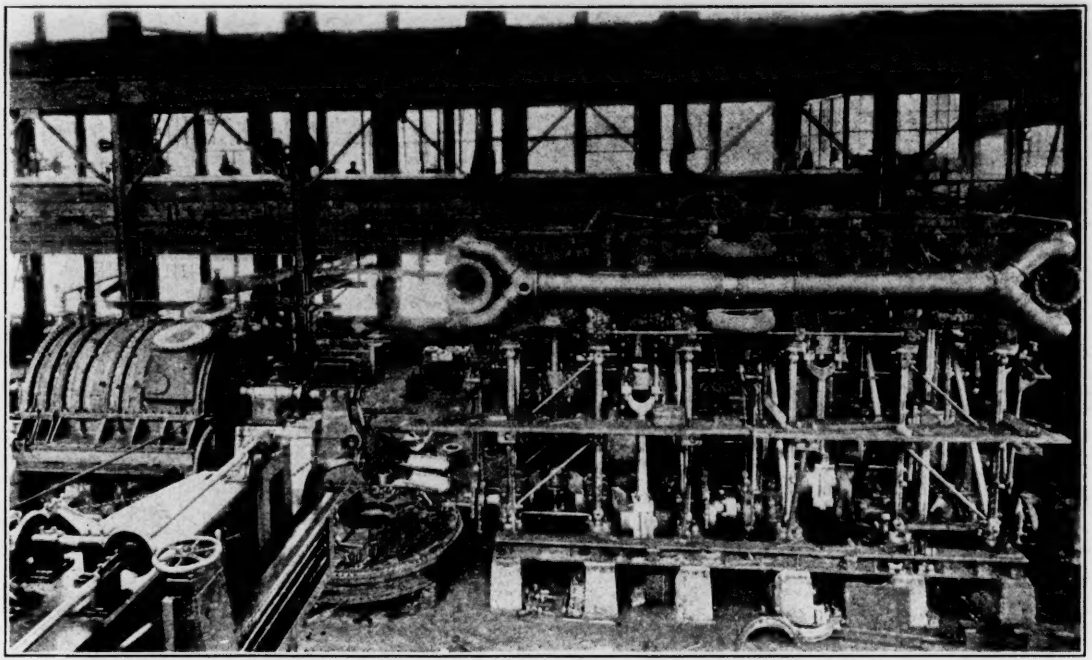
"19. That in the stowing of liquid fuel on board vessels whether taken on board for fuel purposes or for transportation in bulk, the compartments containing the crude product should be as few as possible, both for reasons of safety and for facility of delivery and discharge."

"20. That with the use of oil the forcing of a marine boiler should be much more readily accomplished than with the use of coal."

"31. The board regards the engineering or mechanical feature of the liquid fuel problem as having been practically and satisfactorily solved. * * * For mercantile purposes the commercial and transportation features of the problem are existing bars which limit the use of oil fuel in merchant ships. For Naval purposes there is the additional and serious difficulty to be overcome of providing a satisfactory and safe structural arrangement for carrying an adequate supply."

Assisting at these experiments was a young officer, Ensign John Halligan, Jr., U. S. N., commanding the torpedo boat *Rodgers* stationed at Washington with the *Gwin* to assist the board. Until his untimely death a few years ago, Admiral Halligan probably had more experience with the handling of oil fuel than any other Naval officer or enlisted man. The original allowance of $20,000 was insufficient for the entire experiment and was supplemented by a balance of $7,000 left from a previous year. Altogether the tests had cost around $250,000, the balance being made up through the cooperation of private enterprise.

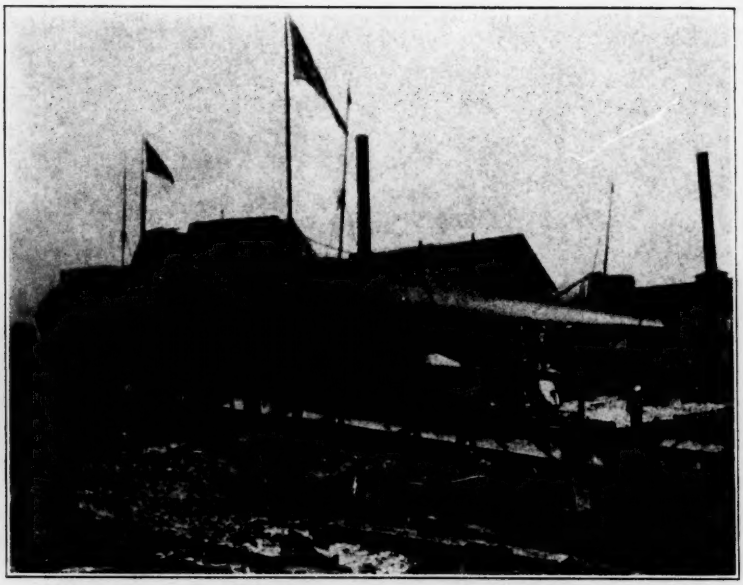
Advance of fuel oil burning now became rapid, though more or less experimental in nature. The Germans, French, and English had each developed a successful mechanical atomizer that was



CURTIS MARINE TURBINE, U. S. S. "SALEM."
8000 B. H. P.

4-CYL. TRIPLE-EX. MARINE ENGINE U. S. S. "VERMONT."
8250 I. H. P.

FIGURE 23.



THE U. S. S. "PLUNGER."
FIGURE 24.

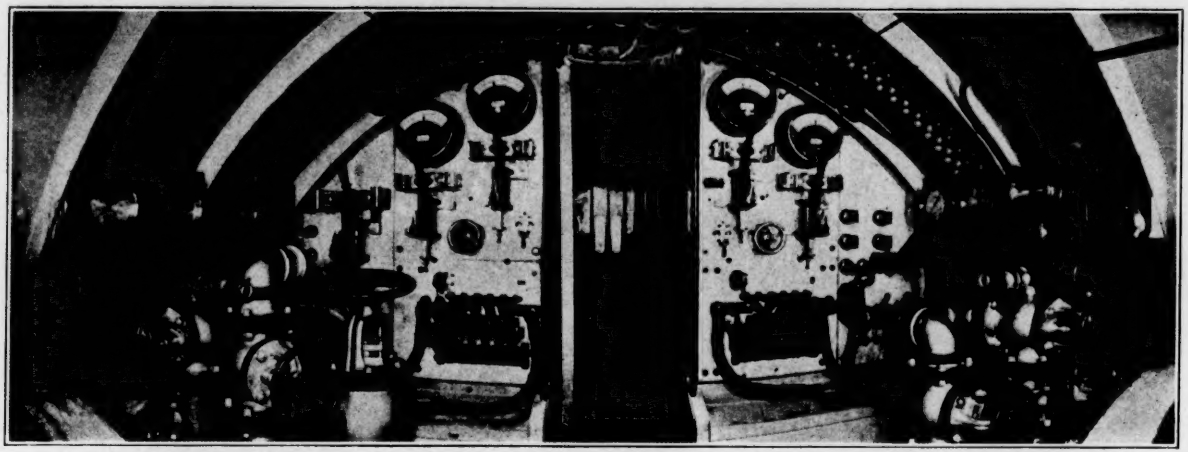
placed in use. In England conversion to oil burning was projected for the battleships, *Mars, Hannibal,* and *Sultan,* and the new *Hibernia* was to be fitted for the storage of oil fuel. In 1905 a note in the JOURNAL mentioned that the British had decided to use oil fuel in all battleships of the Atlantic Fleet, though the Fuel Oil Board stated its use on warships due to the uncertainty of supplies was inadvisable.

On the other hand, the United States adopted an entirely different policy from that of foreign nations. Where their attitude leaned toward conversion of existing installations, the chiefs of the Bureau of Steam Engineering using the support accorded to them by the Liquid Fuel Board became a driving force to limit its use to new installations only. The only exception to this was the conversion of the monitor *Wyoming* to oil burning, the conversion beginning in 1906 and completing in 1909, even to the name, for by the time the alteration was completed her name had been changed to *Cheyenne.* Only fair success was met in the latter conversion, for the *Wyoming* system was dependent upon a somewhat inefficient compressed air system for atomizing purposes, and to accomplish this heavy air compressors were installed, adding their load to that of the auxiliaries. Oil fuel burning really began in 1907, with the letting of contracts for the *North Dakota* and *Delaware.* In these two vessels a serious attempt was made to use oil as a regular feature except that it was planned as an auxiliary to the coal which was the principal fuel. Mechanical atomization was specified to force research in the United States, no such system having been reliably developed here. Tests on European and locally developed mechanical atomizers at the Navy Yard, Norfolk, in 1907, tossed steam and air atomization in the discard.

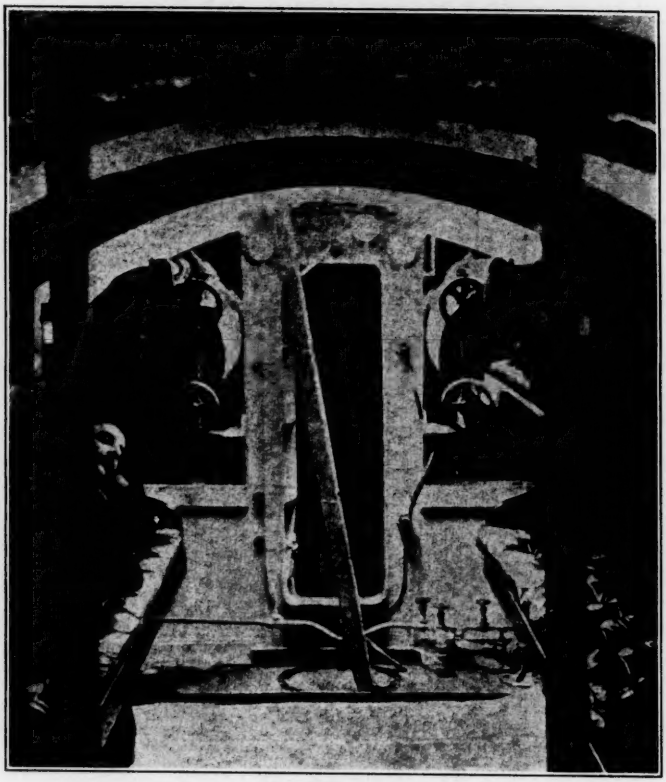
With the question of fuel burning under serious discussion, other phases of the effort toward economy were now brought into the limelight. In the Spring of 1907, a decision was made to send the United States Fleet on an unprecedented cruise around the World, stopping at various ports of call. Heavy criticism was levelled at this Government, but the cruise was made. More of this story will be told later, but suffice to say here that when the ships set out, each ship was to keep a record of its speed, efficiency, and economy, the

amount of fuel burned, hours under forced and natural draft, distance covered, and speed obtained. To retain some order of comparison, the competition was held between vessels of the same class. Eighteen battleships equipped with various types of boilers made the cruise and from their reports an excellent comparison of Scotch and water-tube boiler performance was secured though it is regrettable that at this early date fuel oil burning was not included.

Surface vessels have been described consistently in the preceding paragraphs but nothing has been said of undersea craft, the submarine, in short. The " ninetys " found the submarine being exploited by several foreign nations, though in the United States its development was almost entirely in the hands of private inventors. Principal leaders in this country were Simon Lake and John P. Holland. Historically, the submarine is quite an old idea, several experiments having been tried in the preceding three hundred years. Our own Civil War saw their use and temporary abandonment, with a subsequent revival. To the submarine, too, must be attributed the intensive development of the internal combustion engine as this power unit offered a solution to the difficulties of steam propulsion (the early Nordenfeldts being so driven) in the small hulls available. It is fortunate that the JOURNAL gives several excellent descriptions of these early submarines, for the first ones were not a joint product of the Bureaus of Steam Engineering and Construction and Repair but were treated as a weapon which came under the Bureau of Ordnance. Another anomaly of the submarine situation is the individual attention given by private investigators to this type of vessel in the United States, practically no development being undertaken at Government expense. Again we must reach back into the past and pick out the first of our modern submarines, the *Argonaut, Jr.* (Figure 1), built by Simon Lake in 1894. Its picture makes it appear much like a packing box on wheels. However, it was successful as it meandered along the bottom of Chesapeake Bay. The first of the Navy submarines followed some years later when the sixth *Holland* built in 1896 was tested and accepted in November, 1899, though the price of $150,000 was not paid until April, 1900. She was a small craft with a 75-ton surface displacement, a 45-horsepower gasoline engine for surface use, and a motor drive when submerged. Both units were geared to the



SWITCH BOARD, PRESSURE GAUGES AND BALLAST MANIFOLD VALVES.
FIGURE 25.



LIVING QUARTERS—LOOKING FORWARD.
FIGURE 26.

shaft, furnishing a speed of 7 knots over the ground. The report on this ship emphasized her noisy engine room. Next in order appears to have been a test on the *Fulton,* which was tested by submergence for 15 hours with her crew sealed in. Another early boat was the *Plunger* (Figure 24) built in Baltimore in 1897. Her claim to fame was her steam plant for surface operation consisting of Mosher boilers and triple expansion engines which gave her a surface speed of 15 knots and a submerged speed of 8 knots.

These early submarines were no seagoing Waldorf-Astorias. As far as discomfort was concerned, they probably represented the acme of "barbarism." Little heat was furnished, bridges were small, the conning tower merely an excuse, and as the main shafting was of composition, breakage was common. Also, auxiliaries were driven from the main engine instead of independently as in later boats. To further annoy the "Spartans" who dared live in one of these creatures, cooking was done over an alcohol stove, contrary to all safety regulations. Water was stored in every available tank and water was so rationed out that the crew was able to get two washes a day and all that was needed to drink—unless someone took a bath (Figures 25 and 26).

The "A" boats which followed, the *Adder* and *Mocassin* (Figures 27 and 28) being typical of the class, were tested in shallow and sheltered waters in 1902. They were powered by gasoline engines (Figure 29), the Diesel engine of that date being too heavy and considered not entirely reliable. Not until May, 1908, were our first Diesel submarines authorized, they being the *Skipjack* of the E-class and F-2, *Barracuda.* Several submarine accidents had occurred in these pioneer boats with the United States comparatively free from calamity, though two of the "A" boats had sunk because of water pouring through the open hatches when submerging. The *Adder* in turn had a battery of sixty open top lead cells and when a sudden change of trim took place acid spilled over the tops of the cells. Trim could be further changed on some submarines when necessary by shifting two men from the forward to the after part of the hull.

Adoption of the Bliss-Leavitt 21-inch diameter turbine drive torpedo by the United States furthered the submarine's development. In France, at the same time, a controversy was taking place

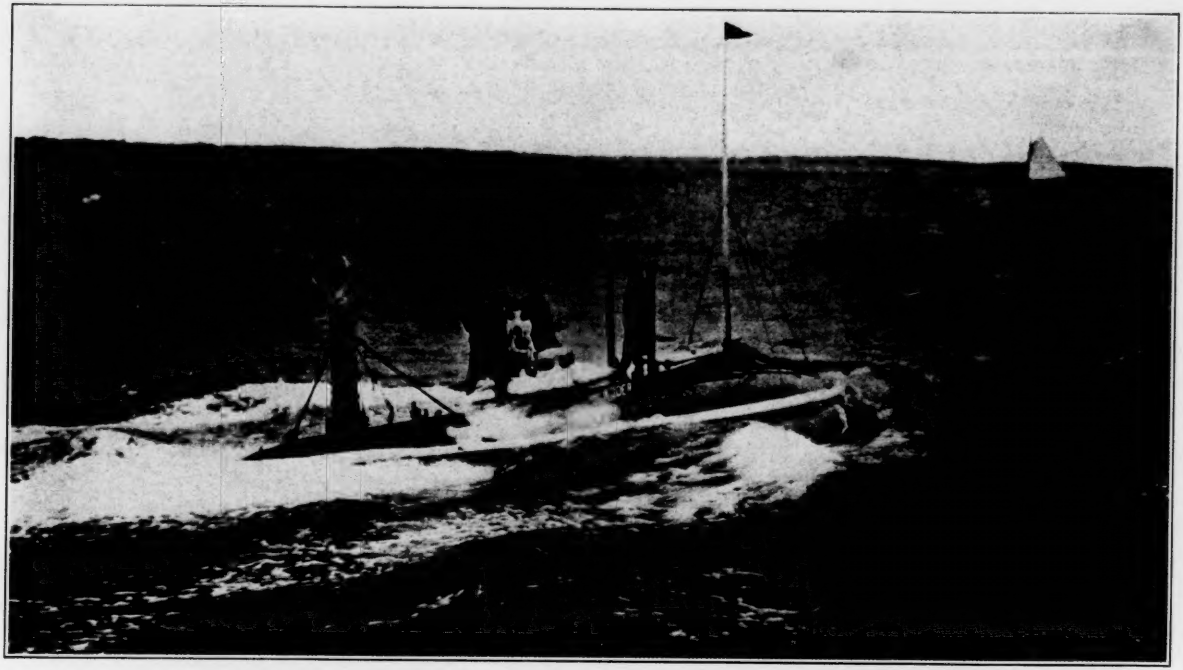
over the relative merits of the submarine and the submersible, a submarine maintaining its underwater position by a change of buoyancy and the submersible performing its duty by driving ahead on forward and after diving rudders. France had and was giving a good deal of Governmental support to the submarine's development and probably had in 1906 more submarines than any other nation.

To give a full perspective of the broad engineering picture during the 1898-1908 period one must include wireless telegraphy, though the tale of its development would create a volume of its own. Hertzian waves, the basis of all radio, had been discovered in 1888. The late Signor Guglielmo Marconi picked up the trail from this point and in 1896 applied for his first patents in England. Our JOURNAL does not give much of this history except for small snatches here and there. Probably the lack of descriptive articles may be attributed to the fact that radio was not a Bureau of Steam Engineering project but belonged to the then Bureau of Equipment. However, to preserve continuity in our history, radio should be included here and recourse has been made to other contemporary papers.

Three British warships, the flagship *Alexandria,* and the cruisers *Europa* and *Juno,* were equipped by Marconi with his apparatus, and in ensuing experiments successful communications were maintained up to 74 nautical miles in August, 1899. Later that same year Marconi brought his equipment to the United States when the "New York Herald" used it to report the *America's* cup races between the *Shamrock* and the *Columbia.* A board of four Naval officers had been directed by the Navy Department to observe the working of his system. The report of these officers was taken up and again that same year an installation of Marconi apparatus was made on the armored cruiser *New York,* the battleship *Massachusetts,* and the torpedo boat *Porter,* and a shore station at Navesink Highlands. A special effort was made to determine the effect of interference on exchanges between the ships and the shore station. Judging from reports, interference was encountered, the only drawback to the equipment's general utility. Despite the defect, the equipment amply proved its value in a very pronounced manner. During trials, a man was lost overboard on the *Massachusetts.* The

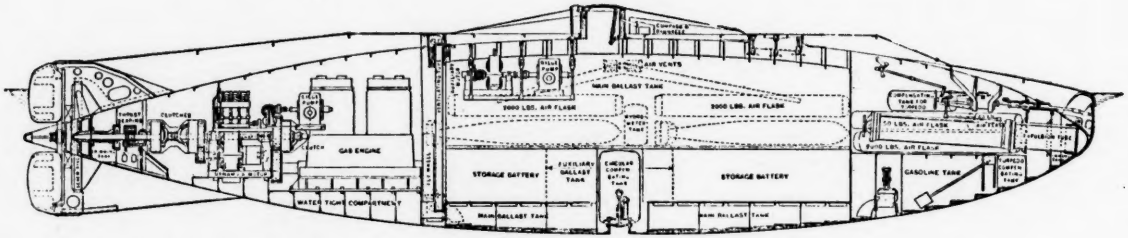
U. S. SUBMARINE TORPEDO BOAT "ADDER" AT THE SPEED OF 8.86 KNOTS ON THE SURFACE. NOTE THE PECULIAR BOW WAVE AND THE HOLLOW JUST ABAFT IT AND ABREAST THE MAST.

FIGURE 27.



U. S. Submarine Torpedo Boat "Adder" at the Speed of 8.86 Knots on the Surface.
Note the Peculiar Bow Wave and the Hollow Just Abaft it and Abreast the Mast.

Figure 27.



CHIEF CHARACTERISTICS OF THE SUBMARINE BOATS "ADDER," "GRAMPUS," "MOCCASIN," "PIKE," "PORPOISE" AND "SHARK."

FIGURE 28.

New York, which was following, was notified by radio, whereupon she picked up the man, drenched but sound. Upon conclusion of tests on November first, 1899, further trials were recommended.

Not much more was done in 1900 except to install a Marconi unit at the Naval Torpedo Station, Newport, Rhode Island, for instruction of officers and enlisted men. Many commercial concerns were entering the field, particularly the Slaby Arco in Germany, and the Ducretet system in France, but on the whole, because of exaggerated claims made, the Bureau of Equipment hesitated to adopt any system, though it determined to discontinue the homing pigeon service as soon as some definite system was decided upon.

The next year, a retired Naval officer living in Paris was detailed to investigate the European radio situation. As a result of this officer's reports two of each of the four leading European systems were purchased for competitive trials followed by purchases of the British Lodge-Muirhead and the American de Forest equipments. The Marconi system was so hamstrung with licensing agreements and royalty payments that its purchase was not undertaken. After a temporary setback, when the Bureau of Equipment was unable to secure sufficient officer personnel for radio work, its development went forward rapidly, the Chief of that Bureau, Admiral Bradford, now making the first move on the part of the United States toward establishing a definite radio plan by asking that the *Pennsylvania* class of cruisers have their masts and rigging so arranged that wireless could be installed.

To carry out the plan which contemplated competitive tests of the six equipments purchased, a board of five officers was appointed in August, 1902, to make a series of tests, the instructions requiring:

1. A test between two stations. Washington and Annapolis were selected for this part.

2. A test between Annapolis and a moving ship on Chesapeake Bay.

3. A test between two ships at sea, and at a considerable distance from land.

A year later, the report of these tests was submitted, with the Slaby-Arco unit being pronounced superior. Seven sets were then

ordered for as many ships, and thirteen additional were ordered for shore installation. Almost at the same time, a preliminary "International Wireless Telegraph Conference" was held in Berlin to bring about some agreement on international radio usage, define the status of shore and ship stations, and standardize methods of procedure. Although the United States had sent representatives, it did not become a signatory party until the spring of 1912.

More ship and shore Naval stations were planned and established in the following year, a peculiar feature of the shore stations being their geographical proximity. Fortunately, many of the shore stations were never built because the range of sets being developed had increased to such a degree that intermediate stations were found unnecessary. One feature worthy of mention here is the proposal in 1904 to establish a time signal service in connection with the Naval Observatory in Washington and also a storm-warning signal service in cooperation with the Weather Bureau.

1904 is also notable in that it marks the first consideration of the United States radio service. With almost every Government department establishing its own units and commercial stations mushrooming over the seaboard, the President appointed the Inter-Departmental Board to rectify a sadly muddled situation. Upshot of the Board's report resulted in recommendations that the Navy Department install a complete coastwise wireless telegraph system to cover the coasts of the United States, its insular possessions, and in the Canal Zone. Where the Army and Navy encountered mutual interference, they were to settle between themselves. Governmental regulation for private communication systems was also recommended, by requesting the Chief Executive to forbid erection of such stations where they interfered with the military services until Congress granted some form of legislation.

Not much has been said about ship radio stations except to mention that units were installed. The *New Hampshire* now became an integral unit of the radio service, for in her building there is found the first definite attempt to prepare planned radio facilities in a ship under construction. Commercial ships were also given an incentive to install radio systems, for in 1905 the first attempted time signal was sent out through cooperation of the Western Union Telegraph Company and the Naval Observatory. The chain of

coastal radio stations gradually increased, for that year marked establishment of the Naval radio in the Canal Zone, Honolulu, Hawaii and the Island of Guam. The increase in range is further shown by Point Loma's reception of a communication between the *Connecticut* off the east coast of Cuba and the Pensacola Station. Comment was made that this was probably the longest reliable distance up to that time. Not much more remains to be added except that ranges of transmitters increased enormously, a high-power station was to be located in Washington and capable of communicating with the fleet no matter where it was located, and that the frequency bands were becoming so cluttered that definte regulation was necessary.

Simultaneously, with the improvements and additions to ships and equipment, research and experimentation began to assimilate and coordinate itself in the Naval service. Leaving out the various experimental boards such as the Fuel Oil Board and the miscellaneous tests being undertaken at several locations, the Navy now began to centralize its developmental and testing facilities. With the Act of 1897, a model testing basin was installed in Washington Navy Yard in 1898, the result of several years of agitation. Foreign countries, particularly England and Germany, had had testing basins for years, and in this manner removed the design of hulls from the zone of rule of thumb methods.

In 1900 and 1901, as in several previous years, the Bureau of Steam Engineering's annual report recommended the establishment of an engineering experiment station to further the improvements then being made. Meanwhile, in 1901 the Bureau of Equipment developed at the Navy Yard, New York, an electrical laboratory. In 1903, the 57th Congress authorized the much-desired Experiment Station. The background to this world-famed institution will be of interest as it is the foundation of its varied duties. Probably the true start of Naval experimentation began in 1861 when Congress passed an act providing that no *patented* article for use with marine engines was to be purchased or used on steam vessels of war until it had been passed in a written report by a competent board of Naval engineers. Apparently this was an outgrowth of the Act of 1860, when Congress had entirely prohibited the purchase of patented articles by both the Army and Navy.

Experimentation had been in progress before that time for the Secretary of the Navy's Report of 1842 mentioned a series of copper frauds perpetrated on the Navy and the subsequent employment of a Professor Johnson to make experiments on the quality of copper. Although this early situation applied more directly to the Naval Inspection Service, it makes note of the attention then paid to quality and service. Also among the early experiments is a test to destruction of two water tube boilers in 1872 by a Mr. Stevens. Just four years afterward, Isherwood, who was quite an experimenter, was appointed senior member of a permanent experimental board located at the New York Navy Yard. The board, however, was not successful in continuing its experiments for Congress did not provide any funds, the cost of tests being borne by the inventor or promoter. Naturally, this eliminated many prospects. Further pioneering by the board was out of the question, as its functions were limited to those patented articles submitted for consideration. To add to its handicaps, the board was later dissolved because of the need of its engineer officers elsewhere, temporary boards being appointed as necessary but with the same limitations as the original board. Growth of the Navy after 1882 brought the situation to an acute point. Emphasis as to the need for an experiment station was repeated in each annual report of the Chief of the Bureau of Steam Engineering and, as previously stated, it was the subject of a lecture before the Naval War College in 1895.

The constant pressure brought to bear upon Congress from both within and without the Navy finally bore fruit when on 3 March, 1903, an act was passed by the Fifty-seventh Congress to provide the much-needed institution. Two hundred and fifty thousand dollars were made available for an experiment station and testing laboratory in the Department of Marine Engineering and Naval Construction, on Government owned land at Annapolis, Maryland, and one hundred and fifty thousand dollars additional provided for equipment and appliances. Vexatious delays set in, however, for no good location was available on the Naval Academy grounds and a search was made on the other side of the Severn River for a suitable area. This was found, and after some years had elapsed, title to the land was cleared, the building begun, and finally occu-

pied in March, 1908. Meanwhile, preliminary equipment was installed in an old engineering building at the Naval Academy and the early work of the Experiment Station started. An additional asset to the station was the construction of the new engineering and naval construction building at the Naval Academy in 1904, now known as Isherwood Hall.

The Experiment Station consisted of four parts, a "main building" of two parts with offices, laboratories and testing machines situated in its north end and in the southern end a machinery laboratory, machine shop, and other shops. To the east, but connected with the main building, was a boiler house containing a Niclausse and a B. & W. boiler with auxiliaries and a dynamo room. The fourth part, a lean-to, on the north side served as a forge shop and bar material storage. Several additions were later made to the station as the volume of work grew and more space was required.

Standard equipment for testing one would expect to find in an installation of this kind was fitted in the buildings. Two tension-compression machines, a torsion machine, impact machines, oil testing machines, Brinell hardness testers, photomicrograph cameras, etc., were so installed. In addition the station power plant machinery and boilers were deliberately pressed into use for service tests of various packings and other machines offered for test. With a suitable personnel to operate the station, experimental work was divided into three general groups; testing, research and instruction. Allied with these was the repair and maintenance duty associated with things mechanical and further study for the purpose of increasing and improving equipment.

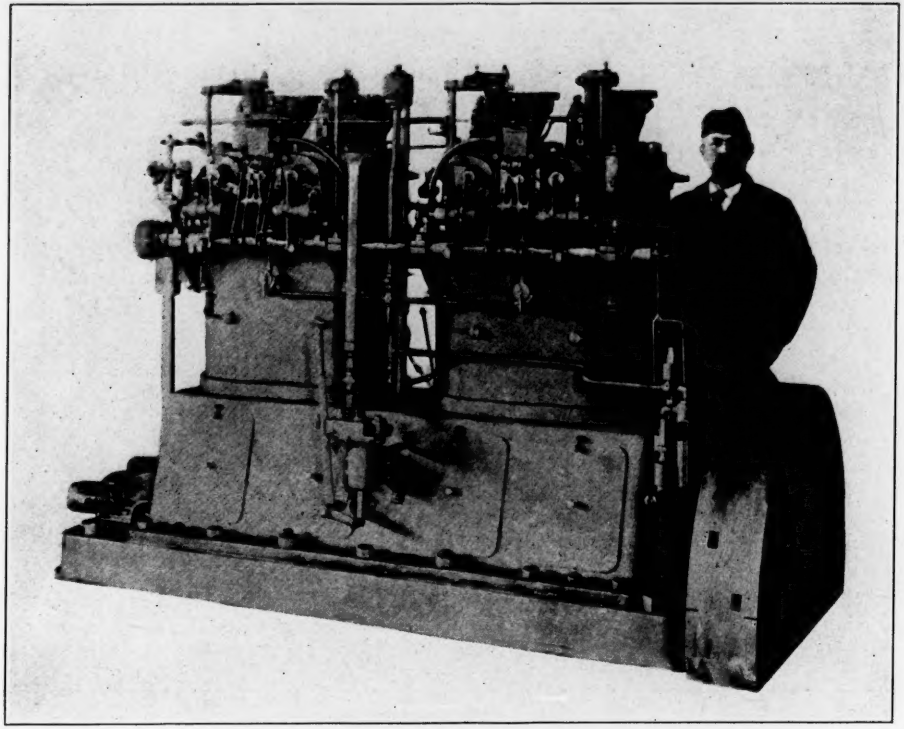
Government departments other than the Navy benefited, too, from the facilities now made available. Performance tests of safety valves for acceptance by the Isthmian Canal Commission, tests of auxiliary emergency radio outfits for the Department of Commerce and Labor, examination of materials for the Bureau of Ordnance, examination of galvanizing processes for the Bureau of Construction and Repair, performance tests of locomotive safety valves for the Interstate Commerce Commission, performance tests of aeroplane engines for the Signal Corps, U. S. Army, may be enumerated from among the tests conducted.

As this period was one of scientific advancement, the Navy De-

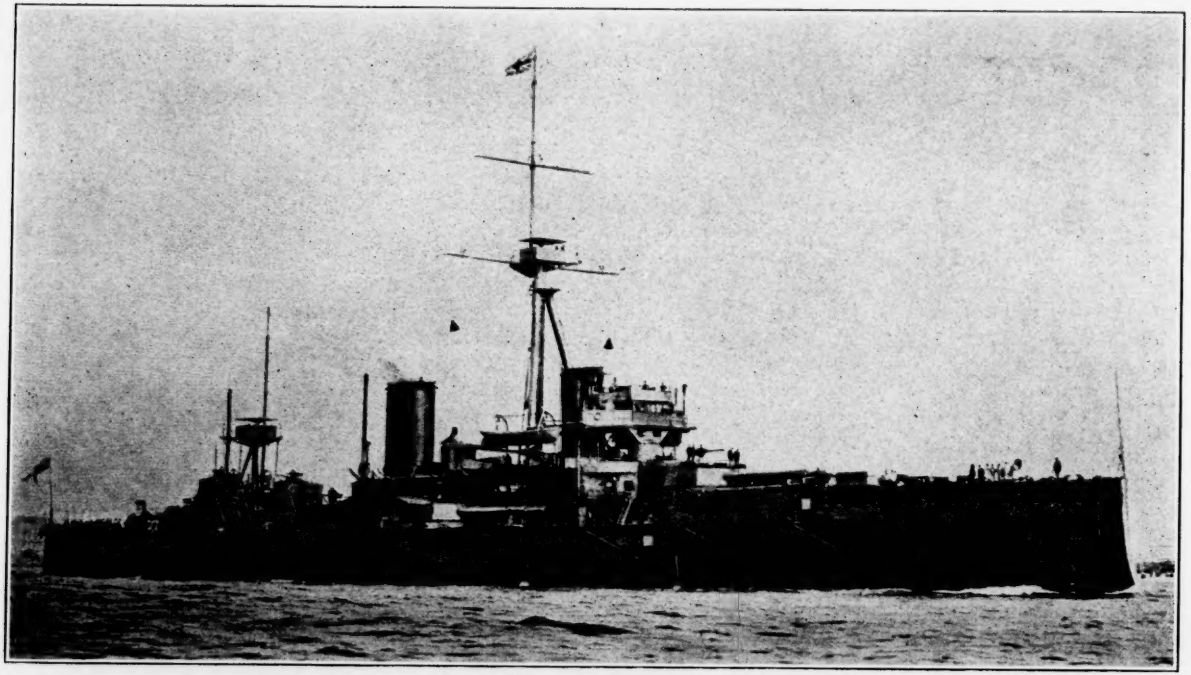
partment was not alone in creating an experimental laboratory, for a year before the Experiment Station was occupied, the United States Geological Survey placed under its Technologic Branch at Norfolk, Virginia, a fuel testing plant for commercial fuel oils. In Germany, tests were being carried on in 1898 on the tensile strengths of various metals at high temperatures (from 212 to 752 degrees Fahrenheit). The weakening effect of extended temperatures on metals was recognized this early, but the effect of high temperatures on the creep of metals was not studied until several years later. Temperatures of the other extreme came under investigation by Professor Dewar in England that same year when hydrogen was liquefied. Goldschmidt followed with his "Thermit" welding process, when he announced its development in Germany in 1901. The benefits of thermit welding were quickly taken advantage of by the shipbuilding industry in the repair of large broken castings. Probably the electrical industry showed greater scientific advancement than the older metal trades. Edison patented his nickel-iron-potash storage battery in 1900 and in the field of electric power, the General Electric brought out its first vertical shaft turbo-alternators, the first of which was put into operation in Chicago early in the first decade of the twentieth century. The machine shops at the Navy Yard, New York, having been destroyed by fire in 1899, the Bureau of Steam Engineering under whom the shops were maintained, outfitted the entire shops and the power house with a polyphase power distribution system to replace the old belted shafting.

Predating the Navy's appointment of a liquid fuel and boiler testing board by two years, the British Admiralty appointed a boiler committee in September, 1900, to investigate boiler defects and to compare the Babcock and Wilcox and Niclausse boilers with the Belleville and other water tube boilers ashore and afloat. On its report made in June, 1904, the Belleville boiler was eliminated from the running by the recommendation that it was not to be fitted on any more ships, the Babcock and Wilcox and Yarrow boilers being recommended instead. Paralleling this investigation, the British ordered experiments on the destroyer *Wolf* in drydock to determine the effect of hogging and sagging as a result of the loss of the *Cobra*. Destroyers, as a result of experiments on the *Star*, were

GASOLINE ENGINES FOR HOLLAND SUBMARINE TORPEDO VESSELS, NOS. 3 TO 8.
FIGURE 20.



GASOLINE ENGINES FOR HOLLAND SUBMARINE TORPEDO VESSELS, NOS. 3 TO 8.
FIGURE 29.



H. M. S. "DREADNOUGHT."
FIGURE 30.

fitted with bilge keels. In the United States measurements of strain and distortion of hulls due to changes of atmospheric temperatures and launching methods were made on the destroyers *Hopkins* and *Hull.*

Taylor of the United States Navy had begun his experiments on the propulsion of ships and the calculation of propellers. His experiments and papers marked the first sincere attempt after Isherwood's experiments at Mare Island thirty years before to secure reliable data on the performance of screw propellers. His efforts were continued at the Washington Model Basin to determine the relationship between the turbine, propeller, and ship. Admiral (then Commander) Dyson picked up the thread of experimentation on propeller design a short time later and made further researches which have been published internationally in subsequent papers.

Foreign navies were not slow in adopting new inventions and incorporating new ideas in their expansion. England led the field with new construction. The cruiser *Europa* in 1898 equipped with Belleville water tube boilers carried steam pressures of 265 pounds, though the British Boiler Committee's work a few years later discarded this particular make for Naval purposes. A feed water regulator was introduced by Thornycroft and much study was given to feed water treatment. For that reason hydrometers and silver nitrate were used by the British for testing feed water salinity. It was not until some years later that similar methods were introduced in the United States Navy.

The next few years saw a considerable standardization in water tube boilers though a few unusual creations were built. A double-ended Yarrow boiler giving a twelve per cent weight reduction was built for the Spanish Navy. White-Forster boilers similar in design to the Yarrow but with round water drums instead of oval were now placed in British destroyers. France had her troubles with the Niclausse boilers when the battleship *Patrie* burned out her funnels. The record states that this was not an uncommon event and that the boiler builders were forced to pay damages. Babcock and Wilcox apparently entered the foreign boiler field through England, when six boilers were placed on H.M.S. *Britannia,* though the record of the JOURNAL states that a British torpedo gunboat was the first to be so fitted.

Despite Admiral Melville's sincere and earnest recommendations, no large three-screw vessels were built after the *Columbia* and *Minneapolis*. Other nations thought differently, for the French launched a three-screw cruiser, the *Montcalm*, and Germany the triple-screw battleship *Kaiser Barbarossa* in 1900. Other than these two ships no outstanding designs appeared for some years. A Russian cruiser, the *Variag*, built by Cramp, set a record on her trials with a sustained twelve-hour speed of 23¼ knots. In Japan, 1902 marked the appearance of the first all Japanese designed and constructed vessels, the cruisers *Niitara* and *Tsushima*. The *Suma* of 1893 was currently supposed to be all Japanese, but as certain features of her construction were of foreign creation, the credit for complete local design passes to the 1902 cruisers.

Launch of H.M.S. *Dreadnought* (Figure 30) on 10 February, 1906, established a turning point in warship construction and made obsolete most of the world's navies. Her armament of ten twelve-inch guns located in five turrets disposed three on the centerline and two diagonally on each side of the ship gave her a considerable advantage over all past battleships. The present arrangement of high and low turrets came in with our *Michigan* and *South Carolina*, authorized in 1906. In the *Dreadnought*, a number of unusual features were incorporated. Her 18,000 tons, 500-foot length, 82-foot beam, and 26-foot draft marked a new high for warship construction. Parsons turbines of a total 23,000 I.H.P. at 300 R.P.M. furnished with 18 Babcock and Wilcox boilers at 250 pounds the power to drive her. The boilers were fitted to burn either oil or coal or in combination. All turbines were direct drive, the two high pressure being located on the outboard shafts, and the low pressure turbines with their backing elements and cruising turbines on the two inboard shafts. A year later a larger vessel, the *Satsuma*, of 19,200 tons was launched in Japan. As this was of the pre-dreadnought type it is very likely the largest of the old design built.

Tonnages of all classes were stepping up, the *Delaware* and *North Dakota* with their lattice masts being of 20,000 tons, and the German *Ersatz Bayern* (*Nassau*), launched in March, 1908, being of 18,000 tons. Destroyers have always been experimental subjects and in their class, their size and speed, too, were increasing. The

Viper, burning 2.49 pounds of coal per I.H.P. per hour, made 33.838 knots on trials with her turbines. It was inevitable that turbines would supplant reciprocating engines for high speed vessels. For a brief interval a scare was given to the turbine builders when a Yarrow-Napier motor boat was tried on the Thames in 1905, and the resulting speed of 30 miles per hour exceeded that of any boat of similar length. The scare was short-lived for the British continued their turbine installations with a designed speed of 33 knots in 1905. Germany, on the other hand, proceeded cautiously, starting her first destroyer, the *S-125,* with turbines in 1906. This was one of six vessels authorized, the other five being equipped with reciprocating engines. As stated in the first portion of this paragraph, sizes increased and in 1907 the British again brought out the *Saracen* and *Amazon,* oil burning destroyers of 893 and 888 tons, respectively, to be followed by the *Swift* of 36 knots and 1800 tons displacement, though 38.3 knots was reached on trials.

Other interesting types of vessels were the British *Cyclops,* a floating dockyard to replace the old *Vulcan,* a former converted cruiser. Battle cruisers made their appearance when the British laid down the *Invincible* and *Indomitable* of 27 knots speed. An experimental producer gas-engined cruiser, the *Rattler,* was also planned. In the British merchant marine the White Star *Laurentic* had both reciprocating engines and turbines for economical operation, while the Germans placed an electric drive in a submarine salvage ship. Submarine development continued as in the United States, the French leading the way in this type, the first submarine Diesel being of French design in 1904, and used in their " Y " boat.

Proceeding apace was the simultaneous successful development of a gasoline lifeboat in England, France, and the United States. A German designed steel works was built by the Japanese Government to make it less dependent on foreign supply. Accidents were not without toll, the U.S.S. *Bennington's* disaster having been mentioned, the French battleship *Jena* blowing up in the harbor of Toulon in 1907, and the Italian liner *Principessa Jolanda* capsizing at her launching in 1907. Rumblings of the coming World War were heard in the Naval race begun by the *Dreadnought* and in Germany's establishment in 1908 of twenty years as the life of a

battleship and cruiser instead of the twenty-five years previously allowed.

The advent of our first turbine-driven battleships brings the section of our Naval Engineering history covering the years from 1898 to 1908 to a proper close. President Theodore Roosevelt's great admiration for the Navy, and his sincere and often repeated conviction that the United States must build and maintain an adequate Navy if the country proposed to insure its prestige as a World power, had already served to crystallize public sentiment as to its "first line of defense," and assured its continued expansion. The next article, therefore, will deal with the expansion which preceded and accompanied the World War, and will close with the commencement of the deflationary period marked by the signing of the Washington Naval Treaty in 1921.

NOTES.

INDEX TO NOTES.

MARINE ENGINEERING PROGRESS.
—The Marine Engineer, London, England, February, 1938.

SEEING THE UNSEEN.
—Mechanical Engineering, New York, N. Y., March, 1938.

ATLANTIC REFINING COMPANY'S NEW TANKER, J. W. VAN DYKE.
—The Log, San Francisco, California, March, 1938.

HIGH PRESSURE BOILERS.
—The Engineer, London, England, February 18, 1938.

MISCELLANEA OF ITEMS OF INTEREST TO NAVAL ENGINEERS.

Explosive Rivets.
—The Aeroplane, London, England, February 23, 1938.

Increasing Use of Chromium Steels in Industry.
—Machinery, New York, N. Y., February, 1938.

New Silent Switch.
—The General Electric Review, Schenectady, N. Y., February, 1938.

The Salvage of the Ex-German Fleet at Scapa.
—Engineering, London, England, February 4, 1938.

The New Graving Dock for the Naval Base at Singapore.
—The Shipbuilder and Marine Engine Builder, London, England. March, 1938.

After the Gas Buggy Age.
—The Industrial Bulletin of Arthur D. Little, Inc., Cambridge, Mass., February, 1938

MARINE ENGINEERING PROGRESS.

The Marine Engineer, London, England, has published in its February, 1938, issue a condensed but comprehensive review of European Marine engineering progress and innovations for the year 1937. Due to lack of sufficient space, this article has necessarily been abridged and the photographs and diagrams have been omitted from the reprint.

Last month we indicated that pressure on our space made it impossible for us to include an illustrated survey of marine engineering during 1937. Progress was of such an interesting character, however, that it is fitting that a fairly comprehensive review should be given. Numerically, the motorship made great progress last year, but on the other hand there was considerable technical development on the steam machinery side which well merits attention. The most interesting technical development of the year was, in fact, in connection with steam machinery. We refer to the strikingly economical improved Bauer Wach arrangement which was first described in "The Marine Engineer" and which has shown steam consumptions of exceptionally low values. For instance, the specific steam consumption during the first test was no higher than approximately 5.1 pounds per I.H.P. per hour, while in a second test with a somewhat lower superheat a figure of approximately 5¼ pounds of steam per I.H.P. per hour was returned. These results were obtained on a relatively small installation of about 1000 to 1100 I.H.P. at about 130 R.P.M. and with a steam pressure of about 800 pounds per square inch absolute and a final steam temperature of approximately 1000 degrees F.

It may be stated that the engine is a four-cylinder three-crank unit with tandem cylinders for the first two stages. This arrangement with the single-acting first high-pressure stage, isolates the piston rod packing of the high-pressure stages from the very severe initial steam conditions. Reheating plays a considerable part in achieving the excellent results which have been obtained, there being in this instance two stages of intermediate heating. Space does not allow of our discussing the engine more fully, but suffice it to say that the Bauer Wach exhaust turbine and the vacuum-producing arrangements are along standard lines.

While it must be conceded that no attempt will be made in practice to offer a machinery installation having a final steam temperature of approximately 1000 degrees F., the development has the significant feature of indicating what can be achieved with modern steam machinery if marine engineers are, as it were, given their head. Actually, two vessels are at present building in Germany with machinery of this type in modified form and with less severe steam conditions. Water-tube boilers of the type which the Deschimag have developed to meet modern requirements will be employed, and these, it is interesting to note, will be fitted with Steinmuller mechanical stokers of a new design which the well-known German specialists have evolved.

A particularly useful marine steam engine development which received a good deal of attention during the past year was the North Eastern reheater triple-expansion engine. Unlike Dr. Bauer's new engine, only one stage of reheating is provided, something like 140 to 200 degrees F. of reheat being employed in the normal installation having boilers designed for a steam pressure of about 220 pounds per square inch and a final steam temperature of some 600 degrees F. The reheater used is of simple design, the engine embodies well-tried North Eastern practice, and altogether the installation is one which, in our opinion, should have a considerable future. Results achieved with the *Lowther Castle* and other vessels so equipped have been wholly satisfactory and there is no doubt that the development is one which

is likely to become increasingly important in the future. Associated with the reheater engine is a new form of combustion chamber superheater of simple form, in which accessibility has been closely considered.

HIGH-TEMPERATURE SUPERHEATERS.

While referring to combustion chamber superheaters it is opportune to remind readers of the attractive design which has been evolved by the Sugden specialists and which has been used in White-engined vessels. Mention of the White installation serves to remind us that during the past year the earlier promise of the White system of combination machinery was fully sustained. The idea has now been thoroughly proved in service and the degree of economy obtained with the latest installations is of a very high order. We have previously mentioned, and we reiterate the view that a particularly attractive cargo steamship installation would result if the White engine were allied to a boiler plant having the design of superheaters referred to and fitted with a suitable form of mechanical stoker.

For some considerable time stoker specialists were not attracted by the prospects of producing a design suitable for use with marine type Scotch boilers, but the success of the Bennis stoker and, more recently, the appearance of the exceptionally simple Riley marine stoker and the Babcock-Erith flue type stoker, has tended to change the situation. The Babcock-Erith stoker has, of course, a great deal of marine experience behind it and it is interesting to note that four of these stokers are being fitted to the steamship *Nicoya,* belonging to Elders & Fyffe's, Ltd. During the past year the Bennis stoker has proved satisfactory in the Manchester liners, where it has been employed for some little time, and it has also proved its worth in the *Anselm,* belonging to the Booth Steamship Co., Ltd. These stokers were fitted to the Howden-Johnson boilers of this up-to-date steamship in a remarkably short space of time and as a result of the change the average service speed has been increased by some 6 per cent, with an appreciable gain in economy and, of course, an improvement in stokehold conditions. German marine engineers and stoker specialists are also giving attention to the marine mechanical stoker, although in this case the water-tube boiler is favored and there is little doubt that this development is likely to be one of increasing importance in the future. The British Taylor stoker, successfully adopted for certain of our own ships, has been taken up by the Japanese. Stokers of this type have been adopted for the water-tube-boilered *Kokuryu Maru* and *Oryoku Maru,* two medium-sized intermediate-type vessels. The stokers are of the standard multiple-retort underfeed type and the boilers are designed for a pressure of about 400 pounds per square inch and a total steam temperature of around 730 degrees F.

FORCED CIRCULATION BOILERS.

Another development of the utmost importance, about which we are likely to hear more in the future, is the forced circulation boiler. Here again, German marine engineers have done noteworthy work, as we have recorded during recent months, in connection with Benson, La Mont, Loeffler, and Schmidt plants for naval and mercantile vessels. One of the most interesting forced circulation installations is that of a La Mont boiler in one of H.M. destroyers, which was exclusively described in our November number. This boiler is now at sea, and if it proves as successful as many of us believe will be the case it is not inconceivable that it will have a great influence upon future practice in connection with the boilering of certain types of naval

vessels. In Germany, the La Mont boiler has already been used in a number of naval vessels, we believe, and some interesting mercantile orders are in hand. The Benson forced circulation boiler has not attracted a great deal of attention for marine work in this country although the performance of the German liners *Pretoria* and *Winduk*, which are provided with Benson boilers, has been entirely satisfactory. The *Pretoria* has been in service for rather more than a year and her two Benson boilers are designed for a working pressure of no less than 1200 pounds per square inch, while the Benson port service boiler has a designed pressure of 360 pound per square inch. The turbines are of the most modern type and the net result is a machinery installation of great compactness, low weight, and high economy. The Schmidt-Hartmann high-pressure boiler is already in service at sea, although to the time of writing we have not been able to obtain any reliable information as to its performance. German engineers are also experimenting with pulverized fuel firing in the La Mont boiler plant of the *Stassfurt*, a combination of considerable interest.

Quite recently the modernized and faster Messageries Maritime steamship *Athos II* has gone into service with the first mercantile marine Brown-Boveri Velox boiler. This boiler has replaced one of the seven ordinary Scotch boilers and is designed for a pressure of 780 pounds per square inch and a total steam temperature of about 850 degrees F. A new extra high-pressure turbine and new low-pressure turbines have been supplied by the Deschimag and a particularly economical machinery installation should result; service performance figures will be awaited with interest. The installation is very interesting in that the existing turbines have also been retained. "Velox" steam first passes through the new H.P. turbine and then about half of this steam goes to the new L.P. casings, the remainder mixes with the steam from the Scotch boilers and is fed to the original turbines. Two sets of reduction gears are employed and the new H.P. turbine may be disengaged (through a Vulcan coupling) when reversing as it has no astern section. A similar coupling is provided between both sets of reduction gearing. Power has been raised from 10,000 to 16,000 S.H.P. and with this increase, using new propellers, a considerable improvement in speed should result.

In connection with reciprocating steam engines one of the most interesting of recent developments has been the completion by Harland & Wolff, Ltd., of their first Elsinore-type combination machinery installation. The Elsinore exhaust turbine, it may be recalled, is noteworthy in making use of a roller chain drive in the reduction gear train and the location of the exhaust turbine on top of the condenser, where it does not take up useful space. The same form of exhaust turbine is used in the new reciprocating steam engine which the Moss Dokk Co., of Moss, Norway, has produced, and installed in a number of vessels. The engine is a three-cylinder compound unit of most compact design, steam distribution being effected by means of slide valves driven by a modified form of Klug single eccentric valve gear.

Mention of special valve gears reminds us that the well-tried Christiansen & Meyer double-compound semi-uniflow engine, which has now been fitted into a large number of vessels, has been improved in the larger sizes by the adoption of a new form of valve gear of the Klug-Spranz type. Several of these engines have been installed in association with a Bauer-Wach exhaust steam turbine and this brings us to another interesting improvement in connection with the Bauer-Wach installation itself.

We refer to the method of driving an auxiliary generator from an extension of the exhaust turbine pinion shaft. The generator is of 300 Kw. capacity and this may be coupled to the first reduction pinion shaft through the small hydraulic coupling. In normal service this coupling is filled and the generator turbine is then in communication with the condenser; the turbine

thus rotates as a unit with the generator. In harbor, however, the coupling is emptied and live steam turned on to the turbine, when the generator may be driven as a port dynamo in the usual manner. A somewhat similar scheme for driving auxiliaries off the Gotaverken turbo-compressor set has been developed fairly recently. With this arrangement, it may be recalled, the turbo-compressor drives, in some instances, a dynamo and feed pump, while in other installations part of the exhaust steam which would otherwise be utilized in the turbo-compressor is by-passed to an auxiliary unit taking the form of a small exhaust turbo-generator set, with which a feed pump is also incorporated.

On the marine refrigeration side one of the most important developments which can be discussed in this review is the multi-temperature system of Thomas Ths. Sabroe & Co., with direct expansion of ammonia. This system enables work at different expansion-temperatures with the same compressor-aggregate so that the various refrigerating places (air-coolers) get the correct temperature without restriction of the refrigerating plane and without special "by-pass" arrangements for the current of air.

In addition to the standard ammonia, carbonic acid, and methyl chloride provision refrigerating plants which Sabroe make, they now also deliver plants with a new refrigerating medium known as Freon. This Freon refrigerating medium is quite harmless, non-odorous, non-poisonous and cannot burn. Thus, ships' provision plants with this new refrigerating medium are safe alike for the crew and the food in the cold chambers.

DIESEL-ELECTRIC DRIVE.

Last year the motorship made further progress, an analysis of which brought to light some interesting facts. In a period of five years, for example, the two-stroke cycle engine has become the predominating type. Whereas in 1931/2 the number of marine Diesel installations was fairly evenly divided between two-stroke and four-stroke cycle engines, last year about 85 per cent of the main engines installed were two-stroke units. Moreover, in the case of nearly every vessel fitted with four-stroke cycle machinery pressure-charging was adopted. Although the present year will probably see a further reduction in the percentage of four-stroke cycle-engined ships, we believe that for small and moderate powered vessels, as well as for tankers, there is not a little to recommend the four-stroke cycle engine. Incidentally, one of the most interesting motorships ordered last year is to have four-stroke cycle machinery. We refer to the Diesel-electric vessel now building for the Hamburg-Amerika Line, in which Büchi supercharged four-stroke cycle machinery will be associated with alternating-current electrical transmission equipment. This ship will be otherwise similar to the *Wuppertal*, which was built some time ago, although the unique "fog" propulsion motors of the latter vessel are not considered necessary for the new ship now building. These vessels are of considerable technical importance because with this latest application of three-phase alternating current to motorship propulsion there seems little doubt that the Diesel-electric system enters upon a new and altogether more attractive field than was the case with direct current transmission. The *Wuppertal* is behaving satisfactorily in service, the anticipated economies have, it is believed, been achieved, and it is the intention of the Hamburg-Amerika Line to adopt this form of drive for five vessels which they have recently ordered. Incidentally, engineers in this country are giving the matter serious consideration, and some patents in connection with Diesel-electric A.C. drive have already been filed in the name of one of our most prominent electrical manufacturers.

GEARED MOTORSHIPS.

Indirect transmission of another form made considerable headway last year and is likely to sustain it in the future. We refer, of course, to the geared Diesel-drive which many engineers prefer to the Diesel-electric system. It is equally flexible, is simple and straightforward, and can be applied to vessels of any power or type, including paddlers. The Vulcan drive made considerable progress last year.

One of the most important geared motorships of last year was the *Gambian*. The *Gambian* has been built and engined by the Deschimag and is propelled by two M.A.N. single-acting two-stroke engines having a total output of 2400 B.H.P. These engines have a revolution speed of 275 R.P.M. and drive a single propeller shaft through hydraulic couplings and single-reduction gearing at a speed of 90 R.P.M. The engines are of the directly-reversible trunk-piston type with inbuilt scavenging blower.

A considerable number of somewhat similar installations were built last year, and in the course of the next few months a comparatively high-powered Vulcan-geared passenger motorship will be completed.

Another most interesting development in this connection was the appearance of the Asea electro-magnetic coupling in association with Polar Diesel engines and single-reduction gearing. This gives an excellent layout, an efficient and compact form of transmission, and many of the advantages associated with the geared drive employing fluid couplings. An interesting feature in connection with this development was the comparatively large number of orders which were accepted for machinery of this type before a single unit had been completed, an expression of confidence which we trust the service performance of the vessels will fully justify. Although most of these ships were moderate-powered single-screw installations using two standard Polar two-stroke cycle trunk-piston engines, twin-screw arrangements of this type have been built, and the arrangement appeals to us as being particularly neat.

While these installations are most attractive, we cannot help feeling that the best is not being obtained from systems of this kind with vessels of the comparatively low-powered slow-speed cargo type. Employed in comparatively high-powered passenger or intermediate vessels, especially if associated with engines having a rather high revolution speed than the 250/350 R.P.M. figure which seems popular, a really attractive layout having many good points would result, and we believe that future progress with this indirect form of Diesel drive will be along these lines.

A very interesting 12-cylinder Sulzer engine of 8500 B.H.P. was evolved for the *Prins Albert*, the new Belgian cross-Channel motorship, this being a single-acting two-stroke with the unusual feature of a separate scavenge pump for each pair of cylinders; these pumps are located at the back of the engine.

In Italy several important marine Diesel installations were completed last year by the Fiat works. Their double-acting engine in its latest form is a well-designed unit with much experience behind it.

One Fiat engine has six cylinders 640 millimeters in diameter by 1160 millimeters stroke and develops 6000 B.H.P. at 119 R.P.M. This rating is very conservative, for the maximum output is nearly 8000 B.H.P. The twin scavenging pumps are driven off the forward end of the crankshaft, while the forced lubrication and cooling water pumps are independently driven. Oil cooling is provided for the pistons, the oil being returned from the piston along the annulus formed between the piston rod and its thin hard steel protective sleeve.

SEEING THE UNSEEN.

The following article from Mechanical Engineering, New York, N. Y., appeared in the March, 1938, issue and is an abstract from the Ninth Henry Thurston Lecture, delivered by R. Merwin Horn of the Massachusetts Institute of Technology at the annual meeting of the American Society of Mechanical Engineers, New York, N. Y., December 6 to 10, 1937. Precision apparatus employing the stroboscope, the high-speed camera, and accessory equipment has been developed to obtain a photograph record of rapidly moving objects.

Humans are gifted with five senses, all of which are important in their daily lives. One of these, sight, which is considered most important, has many limitations not ordinarily thought of. Some of these are the inability to see minute objects, and objects at a great distance.

Scientific investigation has favored us with many instruments to aid the eye in overcoming these deficiencies. The microscope is a familiar example of such instruments. It, as we know, is an instrument with which we can observe minute objects that are normally hidden from our sight because of their diminutive size.

Another marked deficiency in our sense of sight is its inability to see rapidly moving objects. This is the deficiency in which Prof. Harold E. Edgerton and his associates, K. J. Germeshausen and H. E. Grier of the electrical-engineering department of the Massachusetts Institute of Technology, have been interested. Over a period of years, they have developed an instrument, known as the stroboscope, which will aid the eye to see rapidly moving objects as though they were running slowly or even remaining motionless, when in reality, they are moving under their actual working conditions.

The stroboscope consists of an electrical circuit that is capable of storing high voltages in electrical condensers. These high voltages may be released in the form of a spark discharge either through air or a gaseous tube, such as mercury or argon. The resulting flash of light from this discharge is of extremely short duration, approximately 0.00001 second. In this short interval, moving objects can have no perceptible motion. It is apparent, then, that, if we cause a discharge to occur in the proximity of a moving object, it will appear to be motionless.

If an ordinary camera is focused on the moving object and a discharge is created so as to illuminate the object we may obtain, what is commonly called, a "spark" or "stop-motion" photograph. A typical photograph, a bullet, hot gases, and sound waves issuing from the muzzle of a 22-caliber rifle, is reproduced. By taxing our ingenuity, different types of contacting and control mechanism may be devised, making it possible to obtain photographs at any predetermined position in the action of a moving object.

Not only can a single discharge be created, but a series also may be produced in succession at regular frequencies, ranging from a few to several thousand per second. These may be synchronized with the moving object by a suitable contacting device to enable us to study the action of the object and determine whether any irregularities, such as vibrations, eccentricities and the like, exist. We not only can watch these moving objects, but, if our contacting device is of such a nature that we know the exact frequency of the flashing light, we may also measure speed accurately without connections to the moving object, providing this motion has a definite and constant frequency.

It is evident that the stroboscope in itself is not sufficient when we wish to learn something of the behavior of a moving object that has an irregular frequency or completes its motion in such a short time that we are unable to

see what is taking place. Professor Edgerton has developed a unique high-speed camera to operate in conjunction with the stroboscope. Standard 35-millimeter film is used and moves through the camera at 75 frames per second when taking movies at the rate of 1200 frames per second. A commutator is placed on the main drive shaft of the camera and operates, through brushes, the control circuit of the stroboscope, causing one flash to occur for every commutator segment as it passes the brushes. The segments are accurately placed on the commutator so that the film moves the distance of one standard motion-picture frame for each flash of light. The camera has no shutter mechanism but depends solely on the intermittent light for shutter action as well as for subject illumination. In making high-speed motion pictures, the camera is operated at a speed that will give the most satisfactory results depending on the speed of the moving object. Camera speeds can be controlled so that a few hundred or as high as 6000 exposures can be obtained per second with such accuracy that precise measurements of acceleration, velocity, and the like can be made on the film.

Among the applications of the high-speed camera are, for example, precise measurements of bullet velocities in the study of ballistics, investigation of detrimental vibrations in high-speed machines of all types and also in automobile engines and chassis, study of airplane propellers and parts to determine frequency and amplitude of vibrations, and accurate measurement of time intervals to within a fractional part of 0.001 second by the high-speed photography of a syncro clock graduated in thousandths of a second. Even medicine has found uses for this camera in studying the action of high-speed microorganisms. In fact, the applications of the high-speed camera are limited almost only by one's imagination.

(This photograph of a bullet, hot gases, and sound waves issuing from the muzzle of a 22-caliber rifle was made with an exposure of 0.00001 second.)

ATLANTIC REFINING COMPANY'S NEW TANKER, *J. W. VAN DYKE*

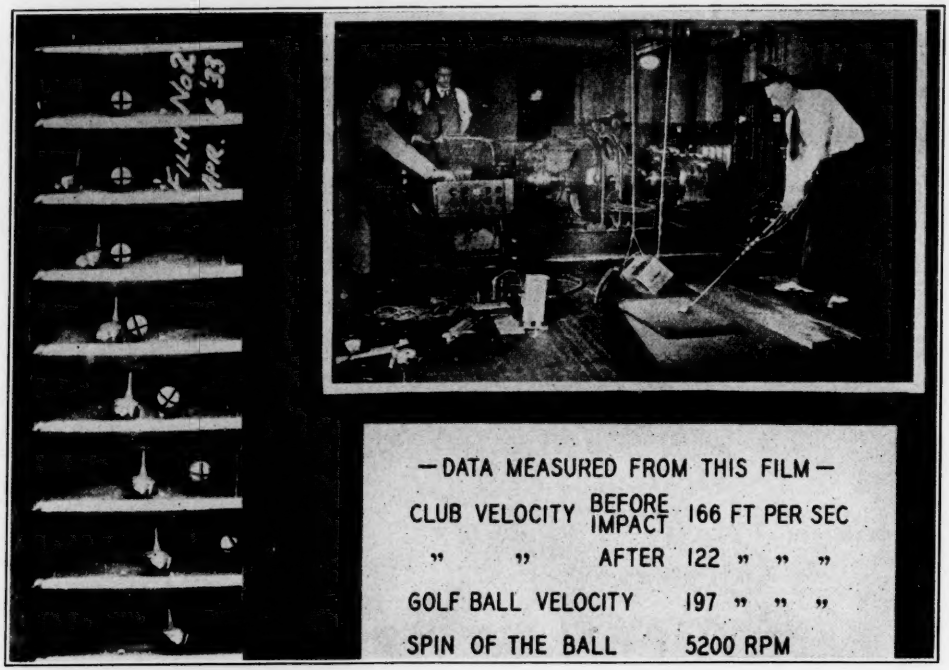
This article, taken from the March, 1938, issue of the Log, San Francisco, California, briefly describes a new oil tanker noteworthy in many respects regarding marine design and construction. The *J. W. Van Dyke* is the world's largest all-welded ship and the first American-built tanker equipped with steam turbine-electric propulsion. The high-voltage alternating-current auxiliaries, deep-well-type explosion-proof cargo pumps, and the electric hydraulic windlass are innovations for this type of ship. The steam pressure is the highest heretofore installed in an American-built ship and the main steam piping is only 20 feet in length. The trials and service performance of this modern ship will be watched with interest by the shipbuilding world.

The Atlantic Refining Company's new 18,500-ton tanker, the *J. W. Van Dyke*, recently made her trial trip from the yards of the Sun Shipbuilding & Dry Dock Company, Chester, Pa. The ship, launched on November 20, is scheduled to go into service between Philadelphia and Texas Gulf ports immediately following successful completion of the trial trip and acceptance by the owners.

In addition to being the world's largest welded ship, the *J. W. Van Dyke* embodies a number of entirely new features in the application of modern engineering principles to marine construction, and is expected to set a record of unusually low fuel consumption. The first American-built turbo-electric tanker, the vessel is the fifteenth electrically propelled ship designed by Atlan-

AN EXAMPLE OF HIGH-SPEED PHOTOGRAPHY.

(This photograph of a bullet, hot gases, and sound waves issuing from the muzzle of a 22-caliber rifle was made with an exposure of 0.00001 second.)


FILM No 2
APR. '33
— DATA MEASURED FROM THIS FILM —
CLUB VELOCITY BEFORE IMPACT 166 FT PER SEC
" " AFTER 122 " " "
GOLF BALL VELOCITY 197 " " "
SPIN OF THE BALL 5200 RPM

TYPICAL LABORATORY SET-UP.

(Making high-speed motion pictures of a golf ball, section of film taken, and data obtained. Film speed, 1000 pictures per second.)

tic engineers during the past fifteen years, making Atlantic the owner and operator of more electrically propelled vessels than any other company in the world.

Many of the engineering principles involved in the design of the new tanker are taken from the best land practice developments of reecnt years that after careful study have appeared applicable to marine equipment. For the first time standard voltage and frequency have been applied to the main propulsion turbo-generator, which is a 3-phase, 60-cycle machine, operating at 2300 volts and supplying its power through a synchronous propelling motor developing 5000 H. P., at the synchronous speed of 90 R.P.M. For the first time in the United States, 650-pound steam pressure is to be employed, at a temperature of 835 degrees F. While this may seem high for marine installation, it is low when compared to the many land installations of 1500-pound pressure at 900 degrees F. temperature.

Boilers are of the simple header type, employing air preheaters and have fully automatic combustion and superheat control. The combustion control is used in conjunction with meters. The superheat control depends upon fully automatic devices and is used for the first time aboard ship.

The engine room auxiliaries are unusual, inasmuch as they are all operated by alternating current. All motors are of explosion-proof type, and of course, are totally enclosed, in fact, all motors are of 440 volts, and this is also true of the two auxiliary turbo-generator sets. A novel feature of the operation at sea is shown in the operation of the auxiliaries when running at a propeller speed of 90 R.P.M. All auxiliary power is taken from the main turbo-generator, the 2300 volts being transformed to 440 volts in the engine room by specially designed transformers.

When the vessel maneuvers, or in other words, when the propeller speed drops below 85 R.P.M., the 440 volts required for auxiliary power is taken directly and automatically from the auxiliary turbo-generator, but when synchronous speed, or 90 R.P.M. is reached, the generator of the auxiliary set automatically becomes a synchronous motor and the auxiliary sets then run as exciters only, for the main turbo-generator. Therefore, all of the power both main and auxiliary, is produced by the main turbo-generator, with the resultant economy of the main turbine.

This actually means that when this vessel is at sea there will be but 20 feet of steam pipe carrying the 650-pound, 835 degrees steam. Thus it is shown how it is possible to pioneer in high pressure and temperature, and yet actually accomplish it conservatively.

The arrangement of the engine room is such as to permit more space around machinery, and more simplicity in piping than has been accomplished heretofore, due to the fact that it has been possible to locate the main turbo-generator on the 'tween deck, thus putting the turbine on the same elevation as the boiler steam header, and shortening the connections between the boilers and the main turbo-generator.

The auxiliary turbo-generators, as well as the entire switchboard and all controlled equipment for auxiliary motors, are also located on the 'tween deck. The main condenser, which is of the twin type having separate water boxes, is flanged directly to the exhaust of the main turbine, and is mounted by specially designed spring feet. This condenser has a divided hot well, and it is possible to shut down either side in case of emergency.

Feed water heating is accomplished in three stages, two ahead of the feed water pumps and one after. Water is fed to the boilers through this system at 350 degrees F. The feed pumps are turbine-driven, multi-stage, centrifugal

pumps, automatically controlled in speeds by pressure, and through automatic feed water regulation connected to and inter-connected with the combustion control system.

The main thrust bearing, which is directly after the main propelling motor, is also a novel application for a vessel of this size. It is a complete journal and thrust roller bearing, the design of which follows along the same line as previously used by The Atlantic Refining Company on its all-welded tankers, the *White Flash* and *Franklin*, which also employ electric drive.

The steering of the *J. W. Van Dyke* is accomplished by electro-hydraulic steering gear, using two complete motor-driven hydraulic pumps, and two complete Sperry Gyro-Pilot after units. There are three distinct methods of controlling this steering gear from the bridge, namely, (1) through the gyro-pilot actuated by the gyro-compass, (2) through the same mechanism controlled by the hand trick wheel, and (3) by an entirely independent lever control, which applies current directly to the auxiliary after unit, without inter-connection through any parts of the gyro system. So long as there is current aboard the ship, which is necessary to run the steering gear, it can be controlled by any of the three methods described above.

In connection with the deck machinery, there have been several departures from the usual practice. In the first place, all deck machinery, which consists of one windlass, two deck winches and three capstans, are of cast steel, no cast iron whatsoever having been employed. The windlass is novel, inasmuch as it is a complete electric hydraulic windlass. Under deck in the forecastle, is located the motor-driven hydraulic pump, and on deck, directly connected to the windlass, is the hydraulic motor.

By this method, perfect control is obtained on the windlass, the motor of the hydraulic pump always running at constant speed. The control is effected by means of hydraulic variation, and it is possible to move the windlass so slowly that the movement is almost imperceptible to the eye. In addition, the relief valve on the hydraulic motor overcomes the danger of damage to the windlass by inertia forces, an inherent difficulty encountered in direct electric drive installations.

A very distinct departure has been made in connection with the cargo pumps. There has been much study, attended by considerable accomplishment, in recent years with regard to the rapid "turn around" of tankers. Based on these studies, it was the management's charge to the engineering and construction department that the cargo pumps be capable of discharging 15,000 barrels per hour. After thorough investigation, it was decided to install centrifugal pumps of the vertical type, sometimes known as the deep-well type, with vertical explosion-proof motors, which are located on deck.

This not only makes possible a very simple pump room located amidships, but results in a feature never before seen in any cargo pump room; namely, the entire pump room is without wires or lights, and is illuminated by totally enclosed floodlights behind glass set in the deck. In the pump room, moreover, there are absolutely no stuffing boxes of any kind on the pumps. The column that carries the shafting also carries the discharge liquid, and this greatly simplifies the pump room piping.

The priming of the pumps under all conditions, is accomplished by a special vacuum system employing three Hytor vacuum pumps, a system which has been used successfully by The Atlantic Refining Company for ten years. The control of the cargo pumps is accomplished by means of explosion-proof "start" and "stop" buttons stationed to the motors. The speed is regulated directly from the engine room.

The vessel is, of course, equipped with the very latest in radio equipment, radio direction finder, and a complete inter-communicating marine telephone system. Cargo capacity of the vessel is 156,000 barrels. Fuel oil bunkers have a capacity of 9,070 barrels. The ship has an overall length of 543 feet, a beam of 70 feet and a depth of 40 feet. Her sea speed will be 13.25 knots.

Following is a list of the principal equipment installed on the *J. W. Van Dyke:*

Main Turbine—General Electric, 6032 H.P., 3600 R.P.M., 600 pounds pressure.

Main Generator—General Electric, 4530 K.V.A., 994 P.F., 2300 V., 60 Cy., 3 Phase, 3600 R.P.M.

Propulsion Motor—General Electric, 5000 S.H.P., 90 R.P.M., 2300 V., Synchronous-Induction Type.

Main Condenser—Ingersoll-Rand Twin Two-Pass, 4775 square feet surface.

Two Auxiliary Turbo-Generators—General Electric, 350 Kw., 450 V. Geared Sets, 3600-1750 R.P.M.

Two Compressors—Ingersoll-Rand, 2-Stage, Air Cooled, 60 C.F.M. each.

Two Boilers—B. & W. Cross Drum, Header Type, 22,500 pounds Hr. at 625 pounds Pressure.

Two Evaporators—Griscom-Russell, Reilly Type, Cap. 15 tons day each.

Evaporator Condenser—Griscom-Russell, Type 8-108, Style A.S.T. Vertical, 49.2 square feet H.S.

Auxiliary Condenser—Ingersoll-Rand, 2-Pass, 800 square feet Surface.

Two Evaporator Feed Pumps—Westco, Turbine-Type, Cap. 1500 pounds Hr., 1 H.P. Motor.

Two Condenser Pumps—Ingersoll-Rand, Centrifugal, 90 G.P.M. each, 15 H.P. Motor.

Auxiliary Condenser Pump—Ingersoll-Rand, Centrifugal, 20 G.P.M., 3 H.P. Motor.

Three Boiler Feed Pumps—Ingersoll-Rand, 8 Stage Centrifugal, 125 G.P.M.-125 H.P. Turbine.

Low Pressure Heater—Griscom-Russell, No. 16,129, Vertical, 194 square feet H.S.

High Pressure Heater—Griscom-Russell, No. 18-110, Vertical, 125 square feet H.S.

Lubricating Oil Centrifuge—De Laval, Uni-Matic, Cap. 75 G.P.H., ½ H.P. Motor.

Centrifuge Heater—Griscom-Russell, No. RR-52, G-Fin Type, Cap. 75 G.P.H.

Two Lubricating Oil Pumps—Schutte & Koerting Gear Type, Cap. 50 G.P.M., 3 H.P.

Two Lubricating Oil Coolers—Griscom-Russell, No. 103-96, Vertical, 61.5 square feet H.S.

Two Fresh Water Tanks—5225 Gals. each.

Propulsion Motor Air Cooler and Fan—Tubular Two Pass, 2350 square feet surface.

Two Circulating Pumps—Worthington, Vertical Centrifugal, 3750 G.P.M. ea., 30 H.P. Motor.

Auxiliary Circulating Pump—Worthington, Horiz. Centrifugal, 1200 G.P.M., 10 H.P. Motor.

Thrust Bearing—Messinger Bearings, Inc., Roller Type.

Bilge Pump—Worthington, Horiz. Self-Priming Centrifugal, 325 G.P.M., 7½ H.P.

Bilge Injector—Powell, 14-inch Screw-Down Check Valve on Main Circulating Pump Suction Well.

Two Fuel Oil Service Pumps—Quimby, Screw Type, 7-8 G.P.M. each, 5 H.P. Motor.

Heating System—Direct Steam Radiation Amidships, Indirect with Forced Ventilation Aft.

Fuel Transfer Pump—Northern, Rotary, 150 G.P.M. each, 15 H.P. Motor.

Sanitary Pump—Ingersoll-Rand, Horiz. Centrifugal, 90 G.P.M., 5 H.P. Motor.

Switchboard—General Electric, Steel, Dead Front Type.

Propeller—Built-Up Type, 4 Bronze Blades, C.I. Hub, Diam. 19 feet 6 inches, Pitch 15 feet 2 inches.

Six Ventilator Fans—Hartzell, Propeller Type, 2-11,500 C.F.M., 4-14,650 C.F.M., 1½ H.P. and 2 H.P. Motors.

Fire and Butterworth Pump—Ingrsoll-Rand, Horiz. Centrifugal, 425 G.P.M. each, 40 H.P.

Butterworth Heater—Griscom-Russell, No. 13-8-150, Horiz., 193 square feet H.S.

Steering Gear—Lidgerwood Electric-Hydraulic, Two-Unit, 20 H.P. Motors.

Windlass—Lidgerwood Electric-Hydraulic, 75 H.P. Motor.

Capstans—Lidgerwood Electric, Worm & Gear Drive, 25 H.P. Motor.

Fire Extinguishing System—Foam in Engine, Boiler & Pump Rm. Bilges. CO 2 for Main Gen., Prop. Motor & Switch Gear.

Radio—Radio Marine Corp., 200 Watt, 200 Miles Minimum Range.

Gyroscope—Sperry, Mark XIV Master Compass.

Compass—Sperry Gyro with 2 Repeaters—3 Magnetic.

Binnacle—(Magnetic Compasses)—Negus Compensating No. 1 and No. 2.

Ice Machine—Carrier-Brunswick, Direct Exp. Ammonia, 2½ ton, 7½ H.P.

HIGH-PRESSURE BOILERS.

The following article is an abstract of an address delivered by Professor A. L. Mellanby, D.Sc., LL.D., before the Institute of Marine Engineers on February 8, 1938, and which appeared in The Engineer, London, England, in the February 18, 1938, issue. The growing application of features embodied in land boilers to marine practice is discussed in this paper. It is shown that if higher pressures are to be utilized, consideration must be given to steam reheaters, purity of feed water, drum design, heat transmission through tubes, controlled circulation, water and steam reserve, and close regulation.

In land boiler practice it has been evident for a number of years that the pressure and temperature conditions of modern power plants are becoming more and more severe. The tendency is perhaps more marked in the United States of America and on the Continent than in this country, but even at home there are several examples of stations to be found in which the working conditions are sufficiently high to satisfy the most fervent supporter of the claim that maximum economy of power production is associated with the highest possible conditions of pressure and temperature.

Along with the pressure and temperature development there has also been a steady movement towards an increase in the evaporative power of each boiler unit, so that we now have examples in land central stations of steam

generators each capable of producing up to one million pounds of steam per hour at pressures and temperatures in the neighborhood of 1300 pounds per square inch and 900 degrees F., respectively.

Accompanying the pressure and temperature increases there have been changes in general design until we now have the modern land boiler with its furnace completely surrounded by tubes containing water (or steam) and with its separate constituent parts of superheater, evaporator, economizer, and air preheater. The feature to be chiefly noted is the modern type of combustion chamber which has developed to its present condition largely from the use of pulverized coal firing. In early examples of such firing the deterioration of the brick lining of the combustion chamber was so rapid that water tubes were first arranged around the walls, in a somewhat elementary fashion, in order to afford some protection to the brick lining. The encouraging results of this treatment, as shown by the greatly increased life of the furnace lining, led to a more rational design of the "water walls" and ultimately to an appreciation that what was originally chiefly a safety device could be made to serve as one of the most valuable parts of the heating surface. It is probable that in the combustion chamber of a modern land boiler, lined on all six sides with water-tubes and burning pulverized fuel, the heat transmitted mainly by radiation to the water ranges from 45 to 60 per cent of the calorific value of the fuel.

The addition of an air preheater was due mainly to the introduction of stage feed heating, which, in its turn, was introduced to improve the efficiency of the working cycle, and also to relieve the low-pressure stages of the turbines from some of the working steam. With the high feed water temperatures thus available some means had to be found for bringing down the flue gas temperatures and consequently an air preheater was fitted so that the gases before passing to the chimney could give up some of their heat to the combustion air.

All of the features just described as belonging to the modern land boiler will also be found in the boilers which are gradually finding their way into marine service. The use of high pressure and temperature is especially remarkable, since it will be found that, contrary to the general predictions made some years ago, pressures and temperatures as high as those adopted in land practice are now being employed in marine installations. If, however, very high pressures are to be employed, then the fact must be faced that reheating will be necessary, and that a further complication will be added to the ship's machinery. As the steam expands in the turbine it first loses its superheat and then becomes wet. It will be found that for a given exhaust pressure the final wetness will increase as the initial pressure rises. Thus, with an initial pressure of 2000 pounds per square inch and the steam superheated to 900 degrees F., frictionless adiabatic expansion to a 29-inch vacuum would produce a 26 per cent wetness at the exhaust pressure. With an initial pressure of 500 pounds per square inch expansion under the same conditions would result in an exhaust wetness of 17 per cent. In actual cases, due to the influence of stage losses, the final wetness would be appreciably less than is indicated by the figure just quoted, but the necessity for reheating the steam at some stage of its expansion when high pressures are used will be readily accepted. The problem, then, is whether to make the reheater part of the boiler and to extract heat from the flue gases, or whether to use the high-pressure steam in a heat exchanger to raise the temperature of the expanding steam to such a temperature that it will not become more than 10 to 12 per cent wet at the exhaust pressure. On land both systems are adopted, but at

sea, so far as reheating is practiced or suggested at present, the steam reheater appears to be the one proposed. In this connection it may be of interest to refer to the reheating installations fitted in the S.S. *Lanchester Castle* and the S.S. *Lowther Castle*. In these vessels steam leaves the boiler at a pressure of 220 pounds per square inch and a temperature of 750 degrees F., and before entering the H.P. cylinder passes through a steam reheater, where its own temperature is reduced to about 600 degrees F. and the temperature of the exhaust from the H.P. cylinder is raised to over 550 degrees F. Here the boiler pressure is only moderately high, and prudence suggests the use of a fairly modest amount of superheat for a reciprocating engine, but the fact that interheating is in use at sea is another indication that the terror of departure from the ordinary, so evident in marine engineering circles, may be now disappearing.

It might now be appropriate to consider what influence the use of high pressure and temperature will have upon the design or running of the steam generating plant. In the first place, it would seem essential that special attention should be given to the purity of the feed water. Under he high-temperature and the high-heat transmission rates to which the majority of the new boilers are subjected, cleanliness of the water or steam sides of the the heating surface is essential. It will be interesting to consider if, in this particular feature, there is any difference in the requirements of individual examples of the new types of boiler, and whether in any case the design of the boiler makes it less sensitive to impurities in the feed.

The question of the steam drum is also one of special importance. Under modern high-pressure conditions the riveted drum is fast disappearing; solid forged drums are largely used, and there are now many firms who look upon the welded drum as standard practice. While these latter methods of construction greatly lessen the difficulties associated with riveted joints in thick plates, yet it must be realized that even in a forged or welded drum of non-symmetrical section serious stresses may be set up which are not disclosed by the usual simple methods of calculation used for stress determination in circular vessels. For instance, the lower half of a steam drum may have to receive the water-tubes, and, in consequence, it will be thicker than the top half. In such a case, due to the non-uniform thickness, bending moments are set up which produce stresses much in excess of those estimated in the usual way for cylinders of uniform thickness. There is also the possibility that part of the drum surface may be at a temperature appreciably higher than that of the rest of the surface. In such circumstances additional stresses will be set up which in very high-pressure boilers must be taken into account. As an example, a case came before the author in which the lower half of the drum of a water-tube boiler was 1 inch thicker than the other half. In addition, there was a fairly large temperature difference between the inner and outer surfaces of the metal, due to the proximity of the lower half of the drum to the furnace gases. When the induced bending moments due to the non-symmetrical section and the heat stresses were taken into account, it was found that the actual stresses were over 50 per cent greater than those estimated by the usual simple theory.

Heat Transmission.—The importance of an understanding of the heat exchange problem cannot be exaggerated, and, indeed, some modern steam generators would not have been possible unless those responsible for their design were familiar with the mechanism of heat transmission. The extent of the radiant heat transmission in the modern boiler has already been indicated, and much work has been done within recent years in researches upon the laws of furnace radiation. As a general rule it may be stated that the

amount of heat Q absorbed through radiation by the comparatively cold walls of the heating surface may be expressed by $Q = C\ (T^4 - \theta^4)$, where T is the absolute temperature in the combustion chamber, θ the absolute temperature of the absorbing surface, and C a coefficient which varies with the circumstances. Obviously the dominating influence is the furnace temperature, and high or low values of heat release will largely depend upon the complete or incomplete combustion of the fuel and upon the amount of combustion air.

It has already been mentioned that, with pulverized fuel firing, and in a combustion chamber lined on all sides with water-tubes, the heat transmitted to the heating surface varies from 45 to 60 per cent of the calorific value of the fuel. The whole of this heat (except for external losses) must pass through the metal walls of the tubes by conduction, and from the walls to the water or steam by convection.

Considering first the heat transference through the metal, it will be obvious that the amount of heat transmitted per unit of surface in unit time will depend only upon $(\theta_1 - \theta_2)$. For the normal boiler $(\theta_1 - \theta_2)$ is comparatively small, and estimates show that if heat is being transmitted through an ordinary carbon steel tube, ¼ inch thick, at the rate of 10,000 B.T.U. per square foot per hour $(\theta_1 - \theta_2)$ will be from 5 degrees to 6 degrees F.

This temperature drop through the metal depends, however, directly upon the coefficient of conductivity of the material from which the tube is made, and it is rather unfortunate that this coefficient for alloy steels is much less than that for plain carbon steels. Taking the coefficient of conductivity K, as measured in B.T.U. per square foot per minute per degree Fahrenheit per inch thickness, the average values at 212 degrees F. for different materials are given as follows:—

For 0.26 carbon steel, 6.46; for a carbon steel with 0.5 per cent molybdenum, 4; for stainless iron, 2.9; and for 18/8 chromium nickel steel, 1.9. It is now common practice to use a molybdenum steel for the high superheats now in daily use, and consequently the temperature drop through the metal for a given heat transfer rate would be more than 50 per cent in excess of that required with a plain carbon steel. It is necessary to keep in mind this temperature difference between the outer and inner surfaces of the tube, since its effect upon the tube stress is very marked with high rates of heat transmission.

It is rather strange that the laws relating to the transfer of heat, under convection conditions, from the fluid to the plate on one side, and from the plate to the fluid on the other side, have been, until comparatively recently, little appreciated by practicing engineers. The first real exposition of these laws was presented by Professor Osborne Reynolds in a paper read before the Literary and Philosophical Society of Manchester in 1874. In his treatment Reynolds pointed out that, apart from radiation, the quantity of heat imparted by or to a fluid to or from an adjacent surface was proportional to the rate at which particles or molecules pass backwards and forwards from the surface to any given depth within the fluid. For conditions usually present in a boiler he claimed that the heat H transmitted per unit surface per unit time could be expressed by $H = B_1\rho_1 v_1\ (T - \theta_1) = B_2\rho_2 v_2\ (\theta_2 - t)$, where ρ is the density, v the velocity of the fluid, and B a coefficient depending upon the nature of the fluid. If the transfer from gases to water is being considered, the subscript 1 would refer to the gas conditions, and 2 to the water conditions. For design purposes, it is often more convenient to change the formula to

$H = B_1 \frac{w_1}{a_1}\ (T - \theta_1) = B_2 \frac{w_2}{a_2}\ (\theta_2 - t)$; where a is the area for fluid flow and w is the weight of fluid passing through this area in unit time.

It has been shown by experiment that water is easily capable of taking from the heating surface all the heat that the gases can put into it, and that once the water is circulating over the surface, increase of water velocity has little effect upon the heat transmission rate. It must be remembered, however, that this refers to water only, and not to mixtures of water and steam. With high rates of heat transference evaporation will take place rapidly, and in all cases the exit ends of the tubes will contain a water-steam mixture. If too little water is present overheating will take place unless the velocity is sufficiently high. The importance of a positive controlled circulation where high heat transmission rates are required is clearly indicated.

[The author then described the La Mont, Velox, Loeffler, Benson, Sulzer, and Schmidt boilers.]

GENERAL CONSIDERATIONS.

To those whose attention has been confined to the standard Scotch boiler the steam and water circuits of some of these modern boilers may appear almost fantastic. Yet it must be remembered that of all the types described there are many examples in practice, and that both on land and at sea much experience in running service has been gained.

One of the first questions arising is that associated with fuel economy, and it might be asked—Does this review show that any one type of boiler has a better efficiency than the other? The answer to that question is that it does not. It will have been observed that whereas some of the boilers described are fitted with air preheaters and economizers, others are not, and thus a true comparison of their relative performances cannot be made. At the same time it might be said that there is no particular reason why one type should be more efficient than another, and that, in fact, well-designed boilers of all classes are equally capable of transforming the heat of the fuel into steam production. From the figures supplied it might be assumed that a fuel efficiency round about 90 per cent is possible with a fully equipped plant.

In the introduction to this paper the necessity of very pure feed water for high-pressure and temperature steam production was indicated, and it must have been apparent throughout the discussion how important it is, with the high rates of heat reception characteristic of the new styles of boiler, that no scale, with its great resistance to heat transmission, should be allowed to form on the inner tube surface. This difficulty of deposits not only applies to the boiler, but may also give trouble in the turbine. It has been found in quite a number of cases that the sodium salts used in the feed treatment volatilize in the superheater, and are deposited on the turbine blading, thus cutting down the power output. Some designs of steam washer are stated to get over this difficulty.

The difficulties associated with steam drums under high pressure were briefly touched upon, and it will have been evident that such difficulties have been appreciated by the designers of most of the new plants. Here, then, the old question associated with water and steam reserve must arise. With the displacement of the Scotch boiler by the water-tube boiler this problem was greatly to the fore, and it seems that there is now another chance of bringing it up in its association with the drumless boiler. Obviously, close and efficient regulation is a necessity; most of the boilers described have their own regulating systems, but space has not permitted their being described in this paper.

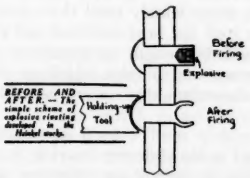
The other point upon which attention will be concentrated is that of weight and volume per unit of steam production.

Finally, it might be asked, although this does not come really within the scope of the paper—Why do we want these very high pressures, and is there any pressure at which we should expect maximum economy?

MISCELLANEA OF INTEREST TO NAVAL ENGINEERS.

EXPLOSIVE RIVETS.—The Aeroplane, London, England, February 23, 1938.

Ever since the first riveted joint which was hard to get at from both sides was designed (and that must have been very early on), what designer or works manager or smith has not dreamed of a magic that might form a head on the inside of the rivet just by tapping the outside? Up to now, the nearest approach to it has been the draw-through type of hollow rivet. Still, with all due regard to their merits, which are very great, they are not a really complete magic, for they are not water-tight, having holes in them, nor can the type of head be varied to any extent.



BEFORE AND AFTER.—The simple scheme of explosive riveting developed in the Heinkel works.

Well, at last the Heinkel people seem to have dreamed a better dream than anyone else, for they have found out how to do this magic. They drill a cup into the end of an ordinary alloy or steel rivet, and fill the cup with explosive. They push the rivet into the hole, and hold a hot holding-up tool against the head. When the rivet reaches 130 degrees C. the explosive goes off.

Now, curiously enough, the rivet does not just go "phut" out of the open end of the rivet and leave it at that. Its reaction is so great that it bulges over the sides of the cup enough to form an adequately strong head. For all I know, a shot-gun would bulge like that instead of bruising one's shoulder if one held it perfectly still. The Heinkel people find it works so easily that they use it not only for parts which are hard to get at behind, but also for quite ordinary parts.

Depending on the size of the rivet, one holds the iron against it for from one to five seconds. That is a pretty short time for riveting, and all with one man. The holding-up tool, which is electrically heated, may have a silver or an aluminum head (copper is unsuitable) which is shaped to fit whatever sort of head the rivet has.

To prevent the heat from spreading throughout the part being riveted, the rivets are covered with a coating of Eloxal, which has insulating properties.

The explosive used is an organic substance and has been specially developed for the rivets. There are no data available regarding composition, but it

causes no corrosion and does no harm whatever to adjacent or opposing members in the structure. The rivets are about 85 per cent as strong as ordinary rivets, if dural is considered. They are thus just about as strong as light alloy rivets which do not require heat treatment before riveting. Dural is used in the hard state when one rivets explosively.

The only other tool required is a means of measuring the combined thickness of the pieces of material to be riveted together, so that one can use a rivet with the correct length of shank. Heads (on the outside) of any shape may be used, and joints may be made watertight.

So it looks as if the dream has come true and that shops will revel in the difficult parts and corners instead of saying "It can't be done!"—or will they? But doubtless, if the designer really takes advantage of the extra leeway thus afforded him he will be able to evolve structures which are impossible to rivet even from one side.

INCREASING USE OF CHROMIUM STEELS IN INDUSTRY.—Machinery, New York, N. Y., February, 1938.

A survey of the types of steel used in almost every important industry—automotive, aviation, railroad, mining, petroleum, chemical, food—indicates that chromium steels are more widely used than ever before. The tendency is to use more chromium steel for heat-resistant and corrosion-resistant applications, as well as for added strength in structural applications. Modifications in the chromium content and suitable additions of other alloying elements are making many of the chromium steels more valuable, more economical, and more widely applicable.

Modifications in the widely used 4 to 6 per cent chromium steels have added to this type of steel a molybdenum-bearing 9 per cent chromium steel suitable for severe service in petroleum refineries and power plants. For high-pressure service, where resistance to shock and the decarburizing effect of hydrogen at high temperature is required, good results are obtained with 1.50 to 2.75 per cent chromium and additions of molybdenum and vanadium. Another modification is a columbium-bearing 2 per cent chromium steel.

The addition of columbium or titanium is responsible for much of the improvement in the properties of many of the chromium-nickel and straight chromium steels, and is the most successful answer research has yet found to certain exacting demands of industry. The prime function of columbium appears to be the control of the carbide constituents of chromium steels. The columbium-bearing chromium steels have found especial application in products fabricated by welding.

Columbium is used in an 18-8 chromium-nickel stainless steel welding rod, and either columbium or titanium in stainless base metal, to inhibit any tendency toward intergranular corrosion that might otherwise be present in or near the welds.

Among the important modifications of the straight chromium oxidation-resistant steels is a new alloy containing 16 per cent chromium and 1 per cent nickel—an alloy that may be heat-treated after fabrication. This material is used in airplane construction.

The analyses of many heat-resistant steels containing 20 to 35 per cent chromium have also been modified. An alloy containing 35 per cent chromium and 7 per cent aluminum has recently been announced as suitable for continuous service at 2300 degrees F.

Another modification consists in the addition of nitrogen to improve the grain structure. Steel castings containing over 20 per cent chromium have been in use for many years in applications where resistance to corrosion, to high temperatures, and to excessive wear is desirable. The addition of nitrogen to such alloys has the effect not only of reducing the tendency to grain growth at high temperatures, but also of refining the grain. This results in a marked increase in the ultimate strength, yield point, elongation, and reduction of area. The nitrogen is added in the proportion of approximately one part to 120 parts of chromium. It is introduced in the form of high-nitrogen ferro-chrome.

Nitrogen is added to chromium steel ingots, as well as to castings, to impart a fine grain and produce a tough and ductile metal especially adaptable to deep drawing operations. Nitrogen-bearing high-chromium steel also appears to possess valuable characteristics for high-quality corrosion-resistant seamless tubing.

The older types of chromium steels are also being used to an increasing extent. The automotive industry is an outstanding example. The aviation field and the railroads are also users of large quantities of such steel.

NEW SILENT SWITCH.—General Electric Review, Schenectady, New York, February, 1938.

The snap of the switch, indicative for generations of progress and the adoption of modern methods, has finally been superseded as the symbol of electric control. After several years of development, General Electric has placed in production a new silent switch in which the contact is made and broken by the movement of mercury.

More important to eventual users than the silent operation is the fact that the new switch, small and compact, has literally nothing to wear out. There is no spring that can be broken and no blades to hammer away. Actual switching elements have operated more than 125 million times in a laboratory life test without failure. Some indication of the possible applications of the new switch in a single field is given by the fact that approximately 15 million house switches are purchased in the United States every year.

The actual switching element in the new device is the size of a small coat button, composed of two metal disks sealed with glass, completely enclosing the mercury make-and-break of the switch. The switch casing and handle are of Textolite. Large binding screw heads will readily accommodate No. 12 wire. The switch can be installed in any standard switch box, and must be mounted vertically

---

THE SALVAGE OF THE EX-GERMAN FLEET AT SCAPA.—Engineering, London, England, February 4, 1938.

From time to time, during the last ten years, we have chronicled the progress made in salving the ex-German fleet, scuttled at Scapa in June, 1919; and some six years ago Mr. E. F. Cox, of Messrs. Cox and Danks, Limited, in delivering the fifth Thomas Lowe Gray lecture to the Institution of Mechanical Engineers in 1932, gave a detailed account of the work accomplished up to that date, which had resulted in the raising of six capital ships,

26 destroyers and a light cruiser. Thereafter the general depression in trade caused a prolonged interruption of the work, but in 1934 Messrs. Metal Industries, Limited, the Glasgow firm of shipbreakers, took up the task, which Messrs. Cox and Danks had relinquished, and proceeded with the salvage of a number of the larger ships, which were lying in deep water. The methods adopted, the obstacles encountered, and the success achieved under the difficult weather conditions which are normal in these Northern waters were vividly described and illustrated at the Royal Institution, on Friday last, January 28, by Mr. T. McKenzie, A.M.I.Mech.E., the chief salvage officer in charge of the operations.

Practically all of the ships had capsized in sinking, said Mr. McKenzie in his opening remarks, and were lying bottom upward in about 20 fathoms of water, so that the only practicable method of raising them was by pumping in compressed air. The equipment available was very complete, including extensive workshops and an oxygen plant at Lyness Pier, and a salvage steamer, the *Bertha*, fitted with air compressors capable of delivering 2500 cubic feet of air per minute. In salving a ship, tubular airlocks, from 90 feet to 100 feet in length, were constructed on shore and placed in position on the wreck by a floating crane. The tubes were built in sections, tapering from about 7 feet in diameter at the bottom, where they were attached to the shell plating by flanges and tap-bolts, to 4 feet at the top, where the actual airlock chamber was situated. The inner door was hinged so as to fall open when the air pressure on both sides was equalized. Ten to twelve men could use the airlock at one time. Recompression chambers were provided on shore, for the treatment of any recurrent attacks of caisson disease. Within a ship's hull the men worked in air at pressures ranging from 40 pounds to 55 pounds per square inch, the time during which they could withstand such conditions varying from about 1¼ hours at 55 pounds pressure to 3 hours at 40 pounds pressure. The air in each compartment was tested by a chemist before the men entered it and if necessary was completely exhausted and changed. The air locks were fixed in position and the necessary guys set up by divers, whose work was frequently interrupted by adverse weather. In one case, the crane had to take out a lock seven times before it could be secured in place.

The first large vessel lifted was the battleship *Bayern*, which was lying upside down with a list of 8 degrees. The *Bertha* was moored about 150 feet from the wreck and the men transported to and from the airlocks in small boats. The ship was first divided into watertight compartments, each with its necessary control valves, and all other valves, pipes, watertight-door openings, etc., sealed. The vessel was nearly ready for lifting when a main drainage pipe burst, allowing a transfer of air which caused the bow to lift and the list to increase to 29½ degrees. It was decided, therefore, to make watertight the longitudinal bulkhead of the starboard wing bunkers, and after some weeks of work the list was reduced to 5 degrees; but then the weather changed, work had to be suspended, and when it was resumed the ship had a list of 6 degrees in the other direction. The port longitudinal bulkhead was then made tight, and this proved successful, the vessel eventually rising to the surface in only 30 seconds after leaving the bottom. She was towed into shallow water (minus the gun turrets, which had fallen out), short airlocks were fitted, masts, funnels and deck erections cut away, and an air-compressing plant installed in a house on the upturned bottom, and in this state she was towed to Rosyth to be docked and broken up. Cutting proceeded from both ends, the complete operation of dismemberment taking between five and six months.

A similar procedure was adopted with the battleship *König Albert*, but eight airlocks were used instead of seven, and both longitudinal bulkheads were made tight at the outset. At this point the lecturer interpolated an effective demonstration with two models in a glass tank, one model having no compartments and the other being sub-divided generally after the plan of the *König Albert*. When air was pumped into the first model it lifted suddenly at one end, sinking again as the air escaped. In the second model the air was held in the separate compartments and the "wreck" floated steadily, bottom upwards. Resuming his account, Mr. McKenzie explained how delicate a control must be exercised in lifting. The bow having been raised to the surface, pumping continued aft, in order to raise the stern; but immediately the stern rose, all available compressor capacity had to be diverted to the bow again, to prevent it submerging as the air already in it was redistributed by the change of trim. The *König Albert* was raised after 8 months' work, and floated without any list. The next ship was the *Kaiserin*, which lay at the bottom with a list of 12 degrees; but as she was a sister ship to the *König Albert*, the men were by this time familiar with her internal arrangements, and the salvage was correspondingly easier. The *Friedrich der Grosse* followed in 1937, and at the present time the salvors are engaged on the *Grosser Kurfürst*, which they hope to raise during the spring of this year.

THE NEW GRAVING DOCK FOR THE NAVAL BASE AT SINGAPORE.—The Shipbuilder and Marine Engine Builder, London, England, March, 1938.

The present situation in international politics lends more than technical interest to the completion of the new graving dock at the Naval Base at Singapore. This dock, it will be recalled, is only part of the main scheme, which, in addition to the usual facilities essential to a large naval base, called for the provision of extensive barracks, aerodromes and fortifications. The dry dock, which will be capable of accommodating the largest warship in the British Navy (H.M. battle-cruiser *Hood*, of about 41,200 tons displacement on load draught and overall length of 860 feet), supplements the huge floating dock which has been stationed at Singapore for the past nine years.

This latter dock was completed in 1928 by Messrs. Swan, Hunter & Wigham Richardson, Ltd., Wallsend-on-Tyne, and towed out East, via the Suez Canal, in two sections. The principal characteristics of this Admiralty floating dock are recapitulated here:—

Lifting capacity, tons (over)	50,000
Length of pontoon, feet and inches	855–0
Width, feet and inches	172–0
Depth over three middle sections, feet and inches	25–0
Depth elsewhere, feet and inches	17–6
Height of side walls above the pontoon deck, feet and inches	50–0
Weight of steel in structure, tons (about)	20,000

Incidentally, the anchorage available at the new base is deep, well sheltered and very extensive, and the spring tidal rise amounts to about 10 feet.

Geographically, the new graving dock is situated near the northern point of Singapore Island on the eastern arm of the Strait of Johore. The distance from the town of Singapore is some 12 miles. No comment is necessary on

the strategic position of the new base, but it is perhaps worth mentioning that the docks at Hong Kong (whose fortifications are limited by the Washington Treaty), Sydney and Fremantle are not large enough for modern capital ships. Hence, as the nearest dock capable of accommodating such a unit was at Malta, it will be realized that the maintenance of a strong naval force in the Far East was difficult, and of little value until a suitable base from which to operate it could be provided.

Preliminary work was commenced on the dock site in 1923; but owing to constitutional changes in England, a cessation of activity was decreed.. The work was recommended in 1928, and on the 14th February, 1938, the graving dock was opened. The inauguration ceremony was performed by Sir Shenton Thomas, Governor of the Straits Settlements and High Commissioner of the Malay States, when he named the dock after King George VI. Accompanying Sir Shenton on board the Government yacht *Seabelle II* were Colonel J. J. Llewellin, M.P., Civil Lord of the Admiralty; Vice-Admiral L. G. E. Crabbe, Commander-in-Chief (Temporary) of the China Squadron, and the Sultan of Johore. In addition to these notabilities, the ceremony was attended by vessels from the Eastern stations, the U. S. cruisers *Memphis, Milwaukee* and *Trenton,* and representatives of Australia, New Zealand, Ceylon, Hong Kong, Sarawak and Borneo.

By courtesy of the Civil Engineer-in-Chief at the Admiralty, who has been responsible for the design of the new graving dock, we are able to publish some details of the dock itself and of the base. When the climatic and geographical disabilities of the location are taken into consideration, these bare figures give but a rough outline of the immensity of the undertaking:—

Area of Naval Base, acres (about)	24,000
Water frontage, miles (about)	4½
Length of graving dock, feet	1,000
Width of dock at entrance, feet	130
Depth of water over sill at low tide, feet	35
Total length of wharf walls, etc., constructed, feet (about)	5,000
Volume of earth excavated, cubic yards (about)	8,000,000
Dredging involved, cubic yards (about)	5,000,000
Concrete deposited, cubic yards (about)	1,000,000
Granite blocks set, cubic feet (about)	250,000

In conclusion, it is perhaps fitting to mention the principal firms who have shared in the difficult enterprise. The construction of the dock was part of the main contract in connection with the Naval Base awarded to Sir John Jackson, Ltd. The entrance caisson has been constructed by Sir William Arrol & Co., Ltd., while the pumping machinery has been supplied by Gwynnes Pumps, Ltd.

AFTER THE GAS BUGGY AGE.—The Industrial Bulletin of Arthur D. Little, Inc., Cambridge, Mass., February, 1938.

In a country as rich in petroleum reserves as ours the term motor fuel suggests gasoline to layman and engineer alike, with an occasional thought given here and there to the growth of the Diesel engine or to alcohol as a gasoline substitute. It is natural that extensive research on gasoline substitutes has been largely foreign. Although lack of American interest in most of this research is amply justified on economic grounds, it may be suggested that if the decision as to when we should show interest in other fuels is left to

that industry now responsible for our motor fuel supply, the coal industry may find that the time-lag in exploiting engineering advances is excessive.

Most foreign developments in motor fuels are motivated by that now strong incentive, the desire for economic self-sufficiency. Coal hydrogenation, the synthesis of alcohols or gasoline from water-gas from coal, alcohol by fermentation—these all yield fuels prohibitively expensive if in competition with imported untaxed gasoline; but they are liquid fuels capable of satisfactory emergency use; in other words, they are gasoline substitutes. Another group falls in a different category—fuels inferior in some respects to gasoline, but of lower cost; they are not true gasoline substitutes.

Three interesting foreign developments in motor fuels of the latter group are economically sound enough to justify interest in this country. These are the use of compressed gas, of producer-gas generated on the vehicle, and of pulverized coal.

The use of gas as such as a motor fuel started during the War, with the provision of large low-pressure collapsible fabric gas bags on the tops of French busses. Developments in metallurgy have since made possible the use of light-weight cylinders to carry compressed gas at 3000 pounds pressure. Those developed in England by the Chesterfield Tube Company for the City of Birmingham Gas Department are eight inches in diameter outside, six feet long, weigh 110 pounds, and carry 350 cubic feet of gas each. Six of these, strapped to the underside of the chassis of a truck or bus, carry a gasoline equivalent of six to fifteen gallons, depending on the quality of the gas compressed. City-gas at 25 cents per 1000 cubic feet is equivalent to gasoline at 9 cents per gallon after allowance for the cost of compression to 5000 pounds and for fixed charges on compressor equipment; natural gas at 25 cents per 1000 cubic feet is equivalent to gasoline at 4.5 cents per gallon on the same basis. With the present tax on gasoline and none on gas, it appears that a gas company could make money and a transport company in the same city could save money by the use of compressed gas.

British experience over a period of several years with hundreds of busses has been very favorable. Gas is claimed to be the perfect motor fuel from the standpoint of ease of starting, freedom from vapor-lock, smooth and economical idling, good acceleration, freedom from gum troubles and carbon deposition, absence of crank-case dilution, and low carbon monoxide content of the exhaust.

Producer-gas, made on the truck as needed, is not as satisfactory as gasoline substitute as is compressed gas; neither is it as expensive. Despite producer-gas operated vehicles having been labeled in this country as "heavy, cumbersome, unsightly, of reduced overall reliability,"—a fair description of the gasoline engine of a generation ago—they have received widespread study and commercial use in England, Germany, Japan, Italy, and South Africa. The MacDonald cross-draft producer on a truck by High-Speed Gas, Ltd., in England, the Svedlund and Imbert down-draft producers in Germany, and the Koela up-draft producer in South Africa are examples of important commercial developments.

Fuel used varies from corncobs to wood, wood charcoal, low-temperature coke, non-caking bituminous coal, and anthracite. Starting from the cold requires from three to five minutes, and necessitates the use of a battery-operated auxiliary blower or initial operation on an auxiliary gasoline supply. Once brought up to temperature, however, the vehicle may be stopped for several hours and started up again without relighting the fire. Starting can undoubtedly be made more automatic with further development of the unit.

The low calorific value of producer-gas air mixtures (70 versus 95 for gasoline-air) is partly offset by the higher permissible compression ratio, up

to 10. The net difference is a 15 per cent decrease in power output per unit displacement volume of the engine; allowance is made for this by increasing the cylinder bore of the engine about 8 per cent. Hoppers are built to carry a 200-mile coal supply, comparable with a gasoline engine. Ashes are dumped approximately once per hopper-filling.

Tests on a five-ton lorry at an average speed of 23 miles per hour indicated a fuel consumption of 1.69 pounds of anthracite pea coal per mile which, at $10 a ton for coal, is equivalent to 0.8 cents per mile. The lorry handled very well in traffic and was just as flexible as a gasoline-operated truck. Other experience with many thousand such vehicles in Europe and the Orient has led to claims of fuel costs as low as one-sixth that of gasoline (with gasoline roughly at twice its American cost), and half that of Diesel operation.

Pulverized coal as a fuel for internal combustion engines has not so far overlapped the field covered by gaseous fuel or gasoline. Instead, developments have been directed towards displacement, by the coal-dust engine, of the steam boiler-turbine combination for stationary power plants. The objective of early research on the compression-ignition engine cycle was the development of a coal-dust engine, but that work led instead to the Diesel oil engine. Almost continuous research has led in the past few years to several types of powdered-coal engines which are now beyond the experimental stage.

One of these is Pawlikowski's Rupa engine, characterized by the use of a small pre-combustion or ignition chamber. Needless to say, the problems of fuel metering, valve operation, and wear due to ash have been serious ones, and attempts at solving the last of these have led to various complicated air-flushing arrangements. It is claimed that in the present Rupa engine the piston rings and linings will last 4000-6000 hours, although the rigid ash specifications undoubtedly necessary to permit any such claims are not given. Much research has been directed towards producing an ash-free coal by air classification, electrostatic or electromagnetic selection, and even pressure-extraction of mineral matter.

The number of coal-dust engines in Germany has increased steadily since the appearance of the first Rupa in 1916. A thermal efficiency of 31.5 per cent, or 7900 B.T.U. per brake horsepower, is now claimed for the Rupa. With a generator efficiency of 95 per cent, this corresponds to 11,200 B.T.U. per generated Kwh., better than the best modern high-pressure steam plant. Whether the coal-dust engine is capable of replacing the steam-power plant in America is a question which will probably be answered during the next decade.

ASSOCIATION NOTES.

ANNUAL BANQUET.

The Annual Banquet of the Society, marking the Fiftieth Anniversary of its foundation, was held on the evening of April 7, 1938, at the Willard Hotel, Washington, D. C. Nine hundred and eighty-eight members and their guests assembled in the large ballroom, and the room was filled to capacity, with an overflow to the wing balcony. Due to the fact that the ballroom had been recently renovated, with the general announcing system and ventilating system both greatly improved, the heavy attendance was easily and comfortably handled.

The program included the following speakers:

Rear Admiral H. G. Bowen, U. S. N., President, the American Society of Naval Engineers.

Rear Admiral R. R. Waesche, U. S. C. G., Commandant, U. S. Coast Guard.

Rear Admiral E. S. Land, (CC), U. S. N. (Retired), Chairman, U. S. Maritime Commission.

The Honorable J. G. Scrugham, House of Representatives, Congressman at Large from Nevada.

As usual, an excellent program of music was provided by the U. S. Navy Band, led by Lieutenant Benter, assisted by specialties from his orchestra, and by eight young sailors from the Washington Navy Yard, who sang their way into the good graces of the entire gathering.

The Society is growing so rapidly, the annual banquet meets such a happy demand on the part of its members, and the seating capacity of any Washington hotel was so obviously nearly reached by this affair that it is apparent that next year's Dinner Committee must give the most serious consideration to the adoption of a method for limiting the guest list.

However, this year it was a grand affair, and everyone reported a good time, and the hope that he could be with us again next year. We hope that lots who came as guests will come as members.

MEMBERSHIP.

The following have joined the Society since the publication of the February, 1938, JOURNAL:

NAVAL.

Banks, J. O., Lieutenant, U. S. N.

Carroll, D. L., Jr., Lieutenant, U. S. N.

Cowart, K. K., Lieutenant Commander, U. S. Coast Guard.

Dooley, Col. J. J., U. S. M. C.; residence, 11 Broadway, New York, N. Y.

Duval, Joseph B., Lieutenant, U. S. N.

Ford, Charles H. G., Lieutenant Commander, U. S. N. R., President, National Products, Inc., Washington, D. C.; for mail, The Majestic, 3200 16th St., N. W., Washington, D. C.

Furer, J. A., Captain (CC), U. S. N.

Gieselmann, Adolph O., Lieutenant Commander, U. S. N.

McKnight, John R., Lieutenant, U. S. N.

Slingluff, Thomas C., Lieutenant Commander, U. S. N.

CIVIL.

Klafstad, Erling, Chief Engineer, Crosby Steam Gage & Valve Co., 10 Roland St., Charlestown, Mass.

Marchant, Dr. John H., Professor, M. E., Postgraduate School, Naval Academy, Annapolis, Md.

Michel, Rudolph, Bureau of Engineering, Navy Department, Washington, D. C.

Morch, John J., President, King Telegage Corporation, 8030 Narrows Ave., Brooklyn, N. Y.

Ogden, Nelson, Sales Manager, Kingsbury Machine Works, Philadelphia, Pa.; for mail, Longfield, Torresdale, Pa.

Riggs, Oliver C., Kingsbury Machine Works, Inc., 4324 Tackawanna St., Frankford, Philadelphia, Pa.

Sharp, George G., Consulting Naval Architect, 30 Church St., New York, N. Y.

Weaver, Joseph B., Director, Bureau of Marine Inspection, Department of Commerce, Barr Building, Washington, D. C.

ASSOCIATE.

Adams, Harold M., Bureau of Engineering, Navy Department, Washington, D. C.

Carp, Sam, President, Carp Export and Import Co., 220 5th Ave., New York, N. Y.

Chamberlin, Herbert B., Sales Engineer, Fafnir Bearing Company, New Britain, Conn.; for mail, Oakland Ave., Hanover, Mass.

Jenks, G. F., Colonel, U. S. A., Office of Chief of Ordnance, Army, Munitions Building, Washington, D. C.

McCord, H. C., Salesman, Aluminum Company of America, 605 Southern Building, Washington, D. C.

Patterson, M. L., Manager, Federal Department, Sperry Gyroscope Co., Manhattan Bridge Plaza, Brooklyn, N. Y.

Schaeffer, Emile M., 3632 North Ashland Ave., Chicago, Ill.